THE IDENTIFICATION OF BOVINE TUBERCULOSIS IN ZOOARCHAEOLOGICAL ASSEMBLAGES

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THE IDENTIFICATION OF BOVINE TUBERCULOSIS IN ZOOARCHAEOLOGICAL ASSEMBLAGES

Working towards differential diagnostic criteria

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ABSTRACT

The study of human palaeopathology has developed considerably in the last three decades resulting in a structured and standardised framework of practice, based upon skeletal lesion patterning and differential diagnosis. By comparison, disarticulated zooarchaeological assemblages have precluded the observation of lesion distributions, resulting in a dearth of information regarding differential diagnosis and a lack of standard palaeopathological recording methods. Therefore, zoopalaeopathology has been restricted to the analysis of localised pathologies and 'interesting specimens'. Under present circumstances, researchers can draw little confidence that the routine recording of palaeopathological lesions, their description or differential diagnosis will ever form a standard part of zooarchaeological analysis. This has impeded the understanding of animal disease in past society and, in particular, has restricted the study of systemic disease. This research tackles this by combining the disciplines of human palaeopathology and

zoopalaeopathology and focusing on zoonotic disease. The primary aim of this research was to investigate the skeletal manifestation of bTB in cattle, sheep/goat and pig to establish differential diagnostic criteria for its identification in zooarchaeological assemblages. Methods commonplace in human palaeopathology were adapted and applied to zoopalaeopathology, in addition to radiography and aDNA analysis. The results emphasise the difficulties but also the potential associated with the identification of systemic diseases in zooarchaeological assemblages. An approach to the classification of potentially infectious lesions is presented that enables the calculation of crude prevalence in disarticulated assemblages. In addition, the potential for aDNA analysis to shed further light on animal disease in the past is emphasised.

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For my parents

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1. INTRODUCTION: IDENTIFYING THE PROBLEM

'…little work has been carried out to identify tuberculosis among archaeo-faunal material.'

(Mays 2005: 131)

1.1 Introduction

This chapter identifies the problem that forms the foundation of this research (section 1.2). The broader context is then presented (sections 1.3 & 1.4). The primary research aim, research questions (section 1.5) and the research objectives (section 1.6) are outlined, followed by the selection of specific time periods and geographical locations (section 1.7). The chapter concludes by emphasising the research significance (section 1.8) and outlining the thesis structure and organisation (section 1.9).

1.2 Identifying the problem

Palaeopathology in human osteoarchaeology has developed considerably over the last three decades. Unfortunately, progress has been comparatively slow in zooarchaeology, impeded by the disarticulated nature of faunal assemblages and the lack of standard recording methods for palaeopathological conditions in faunal remains. As a result, researchers can draw little confidence that the routine recording of palaeopathological lesions, their description and differential diagnosis

will form a standard part of zooarchaeological practice. Consequently, the study of systemic animal disease in the past would appear to be a futile endeavour. This research seeks to address this by combining the disciplines of zooarchaeology, human palaeopathology and biomolecular archaeology, focusing on the study of bovine tuberculosis (bTB) – a zoonotic disease known to affect both animals and humans.

1.3 Tuberculosis: A disease of considerable antiquity

Although tuberculosis (TB) is a significant health concern in the present day, it is by no means a recent disease. Phylogenic research has traced the genus *Mycobacterium* back some 15-17,000 years (Brosch *et al.* 2002), demonstrating the antiquity of the *Mycobacterium tuberculosis* (MTB) complex. There is osteological evidence supporting the presence of this disease in the early human populations of the Old and New Worlds, including most notably: Neolithic Italy (Canci *et al.* 1996), Iron Age Britain UK (Mays & Taylor 2003) and Pre-Columbian communities of the Americas (Buikstra 1981). However, the inability to macroscopically differentiate between the skeletal lesions associated with the human (*M. tuberculosis*) and bovine (*M. bovis*) strains reduces the appreciation of the impact of *M. bovis* on early human and animal populations.

1.4 Research context: The need for differential diagnostic criteria

There are two publications that outline the potential for the identification of bTB in zooarchaeological faunal assemblages (see Lignereux & Peters 1999 and Mays 2005). However, these only present general reviews of the veterinary literature in relation to the skeletal manifestation of bTB in non-human mammals. The need for differential diagnostic criteria to aid the macroscopic identification of this disease in zooarchaeological assemblages has been voiced several times in the literature: '*Because adequate palaeopathological diagnostic criteria are lacking, it is difficult to determine whether tuberculosis was present in early animal herds using conventional palaeopathological examination'* (Mays 2005: 128) and *'…archaeozoologists unfortunately have not produced very much evidence at all for tuberculosis in wild or domesticated animals from archaeological sites…'* (Roberts & Manchester 2005: 185). These statements very succinctly sum up the necessity that both governs and drives this research and its primary aim.

1.5 Primary research aim and research questions

This research investigates the skeletal manifestation of bTB in cattle, sheep/goat and pigs to establish differential diagnostic criteria for its identification in zooarchaeological assemblages. In order to address this aim, this thesis addresses five specific research questions. These centre on three core components identified as fundamental to the practice of palaeopathology and by extension, zoopalaeopathology: lesion morphology, lesion distribution and differential diagnosis. Because zoopalaeopathology predominantly deals with disarticulated and

fragmented bones - precluding the patterning of lesions - it was also necessary to explore the classification and categorisation of non-specific lesions and their potential relationship to specific infectious disease.

Table 1.1 Research questions

Research Questions	Core component for palaeopathological practice
1. What do tuberculous osseous lesions look like in domestic animals?	Lesion morphology and Lesion specificity
2. Is it possible to establish lesion specificity using aDNA?	
3. What skeletal predilection sites are associated with bTB in domestic animals?	Lesion distribution
4. What other pathological conditions could mimic both the lesion morphology and lesion distribution of bTB?	Differential diagnosis
5. Can non-specific lesions in disarticulated bones be better categorised and highlighted for further investigation?	Lesion classification and categorisation

1.6 Research Objectives

In order to address the research questions and achieve the primary research aim, the principal objective was to compile reference material associated with the skeletal manifestation of bTB in domestic animals to inform the development of differential diagnostic criteria. Subsidiary objectives included: the formulation of a more standardised approach to the study of non-specific lesions potentially

suggestive of infection in zooarchaeological assemblages and the analysis and comparison of such lesions in terms of frequency and crude prevalence. These objectives were targeted in the following ways:

- The collation of information related to lesion morphology and lesion distribution in pre-tuberculin era and modern veterinary texts, in addition to any documented modern case studies to better understand the pathogenesis of bTB in domestic animals
- The use of radiography and ancient DNA (aDNA) analysis to explore lesion morphology and the determination of lesion specificity
- The compilation of illustrations presenting the skeletal lesion distribution associated with bTB in domestic animals and humans, highlighting those skeletal regions most frequently affected
- The formation of differential diagnostic criteria for bTB in humans and animals and presenting this information in reference tables for ease of use and comparative purposes
- The sourcing of relevant zooarchaeological sites and assemblages containing both articulated and disarticulated remains
- The adaptation of lesion type classification outlined by Ortner (2003) and widely implemented in human palaeopathology to the recording of zooarchaeological assemblages

- The comparative statistical analyses of palaeopathological data pertaining to species, site and time period, focused upon highlighting verifiable patterns within the data.

1.7 Time periods and geographical location

Two specific periods in time were selected for analysis: the Iron Age in southern Britain and the Viking Age/Norse in the North Atlantic region, specifically focusing on Orkney and Iceland. Modern and archaeological articulated animal bone groups (ABGs) and disarticulated archaeological assemblages were targeted for study. These time periods were selected because agriculture and, specifically animal husbandry, formed the foundation of their respective economies – placing humans and animals in close and prolonged contact. This provided the potential for zoonotic infection through contact and the consumption of infected by-products. In addition, these time periods provide the opportunities to explore the prevalence of disease in sedentary communities of differing size, whilst the Viking Age specifically permits the exploration of disease introduction to new lands by immigrant populations.

1.8 Research Significance

Bovine tuberculosis provides the ideal medium from which to study the impact of zoonotic disease in past human and animal populations. The provision of reference information and a more standardised approach to the recording of palaeopathological lesions in zoopalaeopathology facilitates the better

understanding and recognition of this disease and others in past human and animal populations. This research paves the way for zoopalaeopathology to progress to the point where a better appreciation of disease frequency can be inferred from zooarchaeological assemblages and the recognition and recording of lesions consistent with systemic disease can become both routine and standard practice in zooarchaeology.

1.9 Thesis structure and organisation

The first half of this thesis (Chapters 1-6) presents a thorough overview of the research context and background information that addresses the wider context of this research. The second half concentrates on the research methods, results and the implications of the results. The development of palaeopathology in zooarchaeology is outlined in Chapter 2, highlighting the problems associated with its present study and the differences between zoopalaeopathology and human palaeopathology. Chapter 3 presents an overview of bTB, its current status as a zoonosis and reservoir of infection in the UK, its pathogenesis and skeletal manifestation in both humans and animals. The different pathological conditions that possess the potential to mimic bTB in both humans and animals are presented in Chapter 4, followed by the discussion of the potential for zoonotic infection in past communities in Chapter 5. Chapter 6 presents the background information to the sites and assemblages selected for analysis, whist Chapters 7 and 8 outline the methods employed related to the recording of the pathological lesions and the implementation of lesion distribution, differential diagnosis, radiography and aDNA

analysis. Chapter 9 presents the results of the research, including the differential diagnosis and interpretation of the pathological conditions identified. This is followed by a discussion of these results and their implications (Chapter 10) and, finally, the research conclusion and recommendations for future work (Chapter 11).

2. ZOOPALAEOPATHOLOGY: A DEVELOPING FIELD OF STUDY

'*While faunal analyses of archaeological sites are, with greater frequency, now including some mention of such pathology, this still is not the rule….*'

(Siegel 1976: 349).

2.1 Introduction

Evidence for disease in the past is a topic of research that has, and still continues, to evoke much interest and debate. Palaeopathology was originally defined by Ruffer in 1910 as '*the science of diseases which can be demonstrated in human and animal remains of ancient times*' (Ruffer 1913: 149). Whilst human palaeopathology has developed considerably over the last three decades, zoopalaeopathology has remained largely static, impeded by the disarticulated nature of faunal assemblages and the lack of standard recording methods. This chapter reviews the status and developing role of palaeopathology in zooarchaeology, referred to as zoopalaeopathology.

2.2 Veterinary medicine in antiquity

The acknowledgment of disease in animals can be traced back thousands of years through the survival and subsequent translation of several key written and illustrated texts. The Egyptian veterinary papyrus of Kahun, believed to be at least 4000 years old and dating to c.1900BC (Walker 1964: 198), represents some of the

earliest documented evidence for the recognition of disease in animals. Several ancient texts dating between 2000BC and 4000BC also attest to an advanced knowledge of veterinary medicine in prehistoric India. The earliest evidence from this region comes from the hymns of the *Atharva Veda*, which details the treatment of worms in cattle. A number of similar texts displaying a wider appreciation of animal health have also been identified; these include the *Asva Vaidyaka* translated as 'equine medicine', *Go Chikitsa* 'treatment of cows' and *Hastyayurveda* 'knowledge of the life of elephants'. The latter also details the diagnosis and treatment of tuberculosis in the elephant (Iyer 1937: 718-720). Further east, in China, there appears to be little surviving literary evidence related to veterinary practice and understanding (Baker & Brothwell 1980: 6). However, the earliest reference to scrofula or *Shu* - the non-pulmonary manifestation of tuberculosis (TB) - most often associated with bovine tuberculosis (bTB) is referred to in the *Book of Mountains and Seas* dating to the 3rd or 4th centuries BC (Lee 1942: 272, 278). Later in the 2nd century BC, in a text entitled *Huai-nan-tze* written by Liu An, the head of a fowl is recommended for the treatment of *Shu* (Lee 1942: 272). The literary sources from ancient Greece portray a consistent, thorough and clinical approach to the diagnosis and treatment of disease. This can be largely attributed to the Greek physician Hippocrates (460 -370BC), who transformed the status of medicine and its study. Although, referred to as the 'Father of Medicine' (Meinecke 1927: 382), Hippocrates was also considered '*one of the fathers of veterinary studies*' having contributed greatly to veterinary medicine (Baker & Brothwell 1980: 7). He is reported to have recognised several animal diseases, including glanders, a contagious disease affecting horses (Baker & Brothwell 1980: 7). After Hippocrates,

animal health was also the concern of two further Greek scholars; Xenophon (430-354BC) and Aristotle (384-322BC). Xenophon was primarily interested in the health of dogs and horses, whereas Aristotle was more focused on zoology in general. During the course of his work, Aristotle produced detailed descriptions of several diseases including most notably, canine epilepsy, tetanus and pulpy kidney disease (Baker & Brothwell 1980: 7; Walker 1973: 315). There were many Latin scholars in the Roman Empire who contributed a great deal to the development of veterinary medicine, displaying an intimate, if not always accurate, knowledge and understanding of animal disease. These included most notably Varro (116 - 26BC), Columella (4 - 70AD), Galen (130 -201AD) and Vegetius (390AD - ?). Varro, described as one of ancient Rome's greatest scientists, authored a staggering 620 books in his lifetime (Karasszon 1988: 92). Although not specifically focused upon animal health, Varro displayed a detailed knowledge of epidemic diseases and clearly understood their contagious nature. Columella was first and foremost an agricultural writer, but his most famous work, a twelve volume specialist agricultural collection known as the *De Re Rustica* included sections on both large and small mammals as well as information pertaining to animal hygiene and healing. He provided advice concerning the prevention of disease spread and strongly believed that sick animals should be isolated from the rest of the herd (Karasszon 1988: 95). Columella and his writings, reportedly influenced by the earlier veterinary papyrus of Kahun (Baker & Brothwell 1980: 8-9), continued to influence the development of veterinary medicine well into the Middle Ages and was even referred to as the '*magic book*' (Karasszon 1988: 97). After Columella, there was Galen who regularly conducted public dissections on animals in Rome, becoming an expert in anatomy and

physiological experimentation, whilst taking animal healing to a more professional level (Karasszon 1988: 98). His early career included a four-year appointment as surgeon to a gladiator school, providing him with ample experience related to the healing of humans and exotic animals as well as providing a plethora of deceased human and animal remains to both dissect and study. His 400 plus works included exceptionally detailed anatomical descriptions of bones, muscles and ligaments (Karasszon 1988: 99-101), knowledge that was undoubtedly influenced by his in depth study of animal anatomy and physiology. Sometime after Galen, a Roman writer by the name of Vegetius became involved in the development of veterinary medicine in the later Roman Empire, but unfortunately, not much is known of Vegetius beyond the two surviving works attributed to him. Of these two works, the lesser known *Digesta Artis Mulomedicinae* is the most valuable in terms of veterinary history. This text provided a guide to veterinary medicine in the latter part of the 4th century AD and was focused, in particular, on the diseases of horses and mules (Walker 1973: 303).

Evidence for veterinary research and understanding in the period after the Romans and prior to the Middle Ages is limited. Later in 1762, the first veterinary school was founded by Claude Bourgelat in Lyon, France (Derry 2006: 215). Thirty years after this, in 1792, the first British veterinary school *The Royal Veterinary College* was established in Camden Town, London (Wickens 2004: 330). The establishment of these educational institutions heralded an era of education and development in this increasingly and highly regarded field of study.

2.3 The development of zoopalaeopathology

The study of pathological faunal remains (both skeletal and those still possessing preserved soft tissue) has been prominent since the 18th century. Esper (1742-1810) was amongst the earliest to refer to its study in fossil faunal remains by reporting on the pathological femur of a cave bear (Brothwell 1969: 310). Following this, into the 19th century, notable studies were conducted by Cuvier (1820), Clift (1823) and Virchow (1870) with Moodie (1927) and Palès (1930) leading the way in the earlier part of the 20th century (Brothwell 1969: 310; Moodie 1967: 35). Into the later part of the 20th century, there was a definite increase in interest but still little in the way of structured development. As a result of this, the majority of publications were restricted to the reporting of individual pathological cases of particular interest. Notable exceptions included works by Harcourt (1971), Wijngaarden-Bakker & Krauwer (1979) and Brothwell (1995). In addition to this, Levitan devised a method for the recording of palaeopathology in ungulate mandibles (Levitan 1985) and Dobney & Brothwell (1987) outlined a method for recording dental calculus in non-human mammal teeth from archaeological sites. However, as promising as these publications were at the time, the methods presented were not widely adopted (Thomas & Mainland 2005: 2) and, therefore, the opportunity to gain comparative datasets for at least one aspect of palaeopathological study (oral pathology) was lost. In 1971, Chaplin in his book, *The Study of Animal Bones from Archaeological Sites* allocated a chapter to pathology, its inclusion illustrating the point that the identification and summary of pathology should be seen as a routine practice integrated within zooarchaeology. Chaplin included a classification of disease types along with brief descriptions and examples

(Chaplin 1971: 108-119), a basic outline that was expanded in Siegel's postgraduate research (1975, 1976) and the later seminal publication by Baker & Brothwell (1980). Although brief, the addition of Chaplin's chapter illustrated a much needed turning point in zooarchaeology. Although, just a year later in 1972, an article published entitled 'Some remarks on the use and presentation of archaeozoological data' failed to list palaeopathology at all (Clason 1972 cited in Siegel 1976: 349). In a review of animal palaeopathology in 1976, Siegel stated that, '*While faunal analyses of archaeological sites are, with greater frequency, now including some mention of such pathology, this still is not the rule….*' (Siegel 1976: 349). Unfortunately, this is still the case in the present day. By comparison the study of archaeological human remains, particularly in the United States of America (USA), was beginning to take a more population-based approach to the study of disease (Mays 1998). With no standardised guidelines established, no adopted methodological frameworks and no comparable datasets, the inclusion of palaeopathological analysis in zooarchaeological investigations was and, to a certain extent still is, largely dependent on the interest of the analyst. In 1980, Baker & Brothwell published a specialised textbook entitled *Animal Diseases in Archaeology*. This formed a pioneering text at the time of publication and emphasised the importance of zoopalaeopathology whilst providing a hitherto unavailable point of reference for the faunal analyst. The publication of this text heralded a significant development, providing important reference information and encouraging the routine recording of pathological lesions. Unfortunately, thirty years later, it is still the *only* zooarchaeological reference textbook available.

2.4 Moving beyond 'interesting specimens'

In recent years interest has greatly increased and an attempt has been made to move beyond what Thomas & Mainland (2005: 2) describe as 'interesting specimens'. This is evidenced by a number of publications and the formation of the International Council for Archaeozoology (ICAZ) Animal Palaeopathology Working Group (APWG). A number of publications summarised by Thomas & Mainland (2005) have sought to improve understanding by highlighting those pathologies that appear regularly within zooarchaeological assemblages, reappraising certain methodological approaches and utilising modern datasets, alongside and in conjunction, with archaeological datasets (Thomas & Mainland 2005:2). These include: the investigation into the frequency and aetiology of perforations in the posterior region of cattle skulls (Brothwell *et al.* 1996), a subject that has since been reviewed using the latest CT scan technology (see Llado *et al.* 2008); the analysis and reinterpretation of the indentations/depressions present on some sheep horncores (Albarella 1995) and the utilisation of both modern and archaeological datasets to further explore traction pathology (Bartosiewicz *et al.* 1997).

2.5 Zoopalaeopathology vs. human palaeopathology

Although a field of research still in need of improvement (Uberlaker 2003: 93), human palaeopathology is well-founded, well-practiced and well-understood. Shaffer and Baker (1997: 256) highlighted the following three reasons for the contrast in zoopalaeopathology:

- A lack of training

- Researchers unfamiliar with nomenclature
- The low number of animal bones affected by disease

The low frequency of palaeopathological lesions encountered in zooarchaeological assemblages is at the root of the problem. This situation largely preludes the provision of specialist training and has resulted in a lack of consistency regarding the application of nomenclature and the use of appropriate terminology.

2.5.1 Zoopalaeopathology: The objectives

Miller *et al.* listed three core objectives related to research in human palaeopathology (Miller *et al.* 1996, cited by Bartosiewicz 2002: 31):

- The diagnosis of specific diseases in human remains
- The analysis of the impact of diseases in human populations through time and space
- The clarification of evolutionary interactions between humans and disease

Bartosiewicz (2002: 31) lists the following three objectives for the study of zoopalaeopathology:

- Diagnosing pathological lesions, understanding their taxonomic variability and developing adequate protocols for their description

- Elucidating a special aspect of the human/animal relationship at a given time/place (mundane animal exploitation, ritual treatment etc.) as indicated by pathological phenomena
- Creating an interpretative framework within which pathological observations can be integrated for the purposes of hypothesis testing

Comparing the objectives outlined above, it is immediately obvious that a different approach to the study of disease in past animal populations is required. The main reason for this is the inability to regularly observe lesion distribution in zooarchaeological assemblages. The two disciplines share a common goal, but the difference in deposition and preservation of skeletal material does not allow the simple transplant of objectives from one discipline to the other. As O'Connor states, '...*we can learn from the mistakes that human palaeopathology has made, and realise from the outset that we cannot simply adapt the procedures of that discipline*' (O' Connor 2003: 195). However, this does not negate the establishment of a common ground, where particular methods can be made applicable for use in zoopalaeopathology, for example, lesion distribution and differential diagnosis.

2.5.2 Zoopalaeopathology: Recording methods

The lack of systemised recording in zooarchaeology, with particular reference to palaeopathology, is rooted within and exacerbated by the nature of zooarchaeological assemblages. In 1992, Simon Davis produced an Ancient Monuments Laboratory (AML) Report entitled *A Rapid Method for Recording Information about Mammal Bones from Archaeological Sites*. Davis advocates

recording only quantifiable bones, therefore, discounting the vertebrae and the ribs. Diseases, particularly systemic diseases, spread haematogenously and are often identified within the highly vascular cancellous bone associated with the vertebral bodies and the metaphyses. In addition to this, periosteal rib lesions are a non-specific indicator of respiratory infection (section 3.12.3). However, by largely discarding these elements, the opportunity is lost to record the frequency of lesion types of particular skeletal elements.

O' Connor's (2000, 2003) *The Archaeology of Animal Bones* and *The Analysis of Urban Animal Bone Assemblages* represent the only recently published texts that provide guidance on the recording and analysis of palaeopathology in zooarchaeological assemblages. Even the core textbook for faunal analysts, *Zooarchaeology* (see Reitz & Wing 1999), only pays cursory attention to this subject, referring the reader to Baker & Brothwell (1980).

The need for a more standardised recording method within zooarchaeology has been, and still is, a definite point of contention (see Vann and Thomas 2006; Vann 2008; Bendrey 2007; Bendrey *et al.* 2008). Presently, there is no definitive structure making it difficult to formulate comparable datasets. The lack of inclusion of palaeopathological observations in some general recording strategies has been addressed on numerous occasions (see O'Connor 2000, 2003) and more recently was the subject of a doctoral thesis *Recording the Facts: A Generic Recording System for Animal Palaeopathology* (Vann 2008).

2.5.3 Zoopalaeopathology: Taphonomy

The morphology of zooarchaeological assemblages are determined by a series of factors encompassed by the subject of taphonomy. Taphonomy forms an extensive area of research in zooarchaeology, taking into account any process or agent that possesses the potential to modify organic remains at the point of death, until burial (if there is burial). In short, taphonomy '*defines, describes and systemises the nature and effects of processes that act on organic remains after death*' (Gifford, cited by Nicholson 2001: 179).

The specific cultural and non-cultural agents that possess the potential to modify faunal remains are illustrated in Figure 2.1. The culmination of these agents serves to heavily modify a zooarchaeological assemblage, completely removing some components, whilst altering others. The majority of assemblages, therefore, comprise accumulations of disarticulated and often highly fragmented bones from multiple animals. The modification of these bones by different agents, both prior to and after burial, diminishes the potential information available from their analysis, including evidence of pathology (Schaffer & Baker 1997:256). Not only does this make it extremely difficult to gain an accurate indication of the original 'death' assemblage (see Reitz & Wing 1999: 110-141), but it also precludes the ability to observe the characteristic patterning of skeletal lesions that are routinely recorded in human remains - a vital stage in the diagnostic process for disease as emphasised by a number of authors (Mays 2005: 139; Roberts & Buikstra 2003: 118; Knüsel & Ogden 2007).

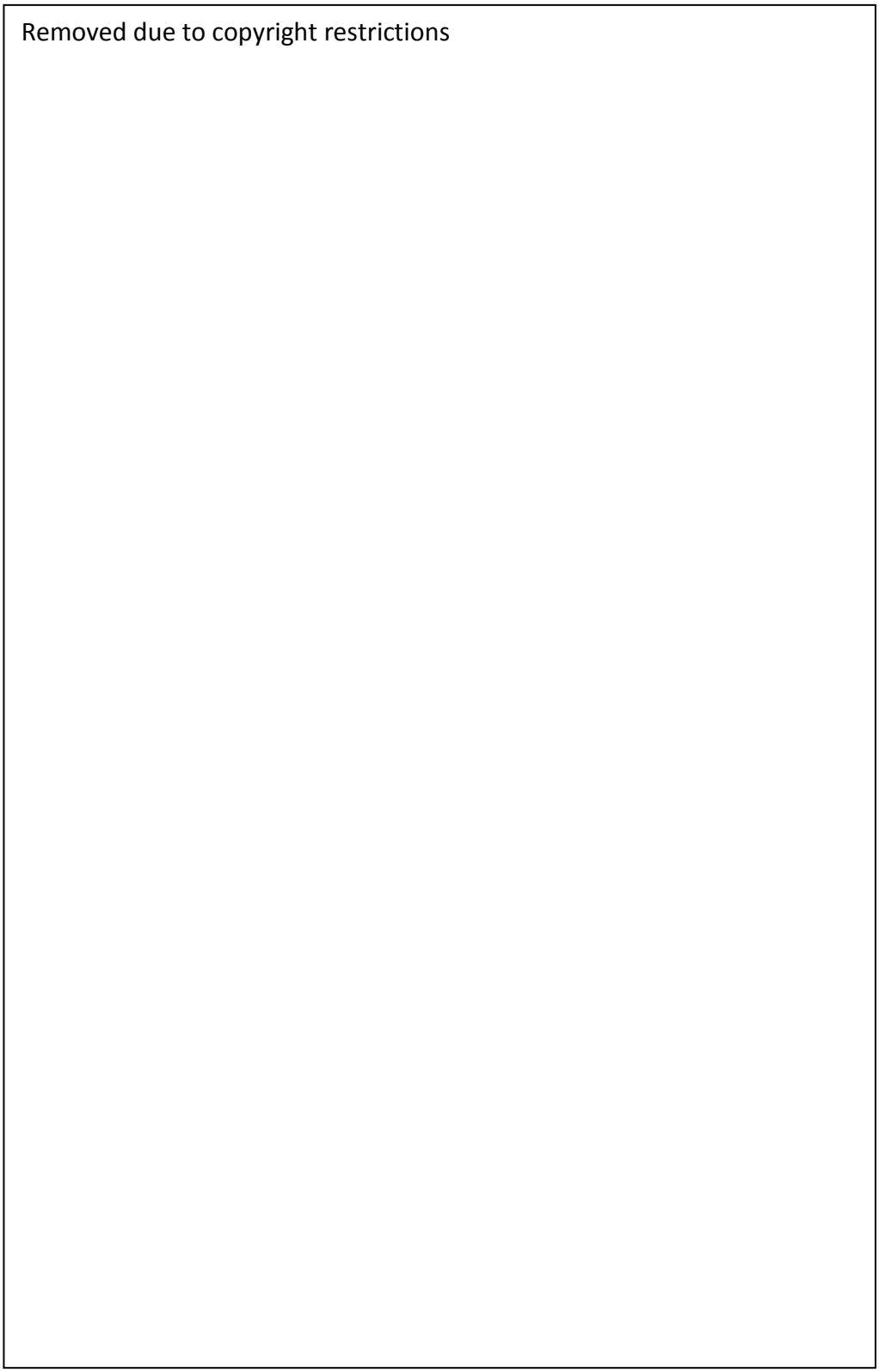

Figure 2.1 Taphonomic agents (Nicholson 2001: Figure 15.1)

2.5.4 Zoopalaeopathology: The osteological paradox

The low prevalence of pathological specimens identified in zooarchaeological assemblages is by no means an unusual occurrence (Shaffer & Baker 1997: 256; Bartosiewicz 2002: 31; Vann & Thomas 2006: 1). There are two important factors that must be considered: the osteological paradox and animal husbandry. In archaeological human and faunal assemblages, the primary indicators of disease are pathological osseous lesions. According to Wood *et al.* (1992) those human skeletons possessing pathological lesions would be deemed 'healthier' individuals than those possessing none. The reasoning behind this seemingly contradictory statement is the fact that if an individual has survived long enough for the skeleton to become chronically involved in the disease process, this would imply a strong immune response to the invading pathogen and survival. Therefore, the remains would represent a 'healthier' individual compared to a skeleton bearing no lesions who succumbed before any skeletal response had occurred (Wood *et al.* 1992: 353). In human palaeopathology, this is described as the 'osteological paradox', a term coined originally by Wood *et al.* (1992). Animals and, in particular, the three main domesticates (cattle, sheep/goat and pig) were, and still are, reared primarily for their meat, by-products, breeding and, where larger animals are concerned, traction. The lives of those animals reared for meat are or remain increasingly shorter than those reared for other purposes. The domestication and management of animals in the present day has meant that diseases are not given the opportunity to progress and an animal's immune system is seldom tested. As a consequence, the concept of the osteological paradox is not easily transferred to

zoopalaeopathology. This is because the cause of death in domestic animals is far more predictable and is almost always the result of slaughter. Therefore, a lack of visible pathology in faunal remains may well indicate that an animal died of an acute disease or that the animal was slaughtered prior to the involvement of the skeleton; but equally, it could also indicate a healthy, disease-free animal that was slaughtered for food or ritual purposes. The implementation of microscopic and biomolecular techniques of analysis (section 2.6), alongside macroscopic methods, provides the means to develop a more representative picture of past animal health.

2.6 Old bones and new methods: The study of palaeopathology

The application of invasive techniques, rather than negating the need to establish macroscopic osteological disease criteria, possess the potential to support such an endeavour in two specific ways: by providing support for a suspected diagnosis or by highlighting the presence of disease in remains with no macroscopic lesions (see Faerman *et al.* 1999). The following sections focus on radiography (section 2.6.1) and ancient DNA (aDNA) (section 2.6.2).

2.6.1 Radiography in Archaeology and Palaeopathology

Radiography forms a pivotal non-destructive method of analysis in archaeology and is widely applied in all fields of archaeological science. The application of x-rays in archaeology is considered a 'potent tool' by archaeological scientists, archaeologists and conservators alike and has grown in application significantly since the late 1960s and 1970s to the point where it is now routine practice, particularly within

conservation (Corfield 1995: 360-1). The popularity of x-rays in archaeology and anthropology is largely due to the fact that as a method of analysis, it is relatively quick and, most importantly, non-destructive. For this latter reason as well as for the wealth of detail available from x-ray images, particularly those obtained using industrial radiography, it is a technique of analysis that has been employed more recently and its use encouraged by researchers in human palaeopathology (see Buckberry & O'Connor 2007). In the absence of soft tissue, osseous lesions associated with dry bone when x-rayed are much clearer, more defined and can be enhanced and manipulated using digital image processing (DIP) (see Buckberry & O'Connor 2007). Therefore, in the present day, industrial radiography forms a key component within palaeopathology, both human and animal, although it is used far more often in the case of the former. The analysis of x-ray images forms the cornerstone of differential diagnosis, aids in the identification of hidden pathologies, such as early stage abscess formation in the mandibles of sheep (Levitan 1985) and highlights potential pseudo-pathologies, for example, the presence of soil within the bones (O'Connor 2002) or the destructive action of beetle gnawing that can mimic lytic lesions in severe cases (Ortner 2003:45).

2.6.2 Ancient DNA (aDNA)

The study of ancient DNA (aDNA) has also become a popular field of research within archaeology and palaeopathology. Higuchi *et al.* (1984) were the first research team to successfully extract and clone aDNA from the skin of an extinct Zebra species, called the Quagga. This was followed a year later by Pääbo's (1985) extraction and cloning of the first example of human aDNA from a 2,500 year old Egyptian mummy

(Spigelman & Donoghue 1999: 353-4). In the mid-1980s, this research demonstrated that it was possible to extract and clone aDNA from remains thousands of years old, but it was not until two years later that aDNA analysis and its application to archaeological research became established as a viable and important scientific technique. The degradation of DNA after death, exacerbated by taphonomy in archaeological remains, is a significant problem. Some remains are found to contain no surviving DNA at all, with others possessing only fragmented traces of only a few base pairs and seldom more than one hundred (Mays 1998: 199). The development of polymerase chain reaction (PCR) by Mullis & Faloona (1987) helped to combat this problem by providing the means to amplify fragmented DNA into quantities sufficient for study. The use of PCR has revolutionised the study of aDNA and, in particular, the study of microbial disease in past human populations. The latter has since developed into a specialist field of study termed palaeomicrobiology, described as a 'new science' by Spigelman & Donoghue (1999: 354).

The ability to amplify fragmented microbial DNA has enabled the study of disease in past populations to move beyond the restraints of purely macroscopic evidence to confirm osteological diagnoses, improve macroscopic criteria and differential diagnosis and providing a better appreciation of disease prevalence in past populations (Spigelman & Lemma 1993: 138; Dutour *et al.* 2003: 151-152). The amplification of different species of bacterial DNA has been significantly aided by the continued development of PCR techniques and the designing of assays to target repetitive insertion sequences in specific genomes; IS6110 and IS1081 for the *M.*

tuberculous (MTB) complex, for example (Eisenach 1990; Thierry *et al.* 1990). This, along with the use of direct sequencing and spoligotyping (strain identification), has enabled specific strains of disease (*M. tuberculosis* vs. *M. bovis*) to be differentiated, something that cannot be achieved by macroscopic analysis alone (Moda *et al.* 1996: 103).

Mycobacterium tuberculosis was the first successful ancient microbial DNA amplification in archaeological human bone displaying pathological change (Spigelman & Lemma 1993). The amplification of bacterial DNA, in particular, has been very successful in relation to archaeological remains and not just associated with dry bone. There have been several examples of *M. tuberculosis* (MTB) complex DNA amplified from mummified tissue (Salo *et al.* 1994; Nerlich *et al.* 1997) and calcified pleura (Donoghue *et al.* 1998). The majority of bacterial DNA analysis in archaeological science has been conducted on human remains and has predominantly focused upon two closely related *mycobacterial* diseases, tuberculosis (TB) and leprosy (see Salo *et al.* 1994; Spigelman & Donoghue 2001; Mays *et al.* 2001; Spigelman *et al.* 2002; Mays & Taylor 2003; and Taylor *et al.* 2007), as well as a smaller number of studies focused upon bacterial aDNA in animal remains (Rothschild *et al.* 2001; Bathurst & Barta 2004 and Bendrey *et al.* 2008).

2.7 Palaeoepidemiology and zoopalaeopathology

Modern epidemiology is a complex field of research focused upon the analysis of disease patterns and disease frequency in living populations of humans and animals (Waldron 2007: 25; Halpin 1975: 1). The sub-discipline of palaeoepidemiology uses

the same basic principles to measure the frequency of specific diseases in past human populations. Unfortunately, this is not a field of study regularly pursued in zooarchaeology, largely due to the disarticulated nature of the faunal assemblages, inconsistent recording methods and the lack of well-established differential diagnostic criteria for different pathological conditions.

Archaeological human and animal assemblages represent non-random portions of dead populations and cannot be organised or controlled in the same manner as modern living samples. This greatly affects the way in which disease is quantified and also the interpretation of the data. This is especially problematic for zooarchaeology where the assemblages are more representative of animal husbandry patterns as opposed to natural attritional mortality. In addition, the assemblages recovered from urban sites will contain animals from several herd populations. For example, '*In York, the sample represents the population of livestock brought into the city, and not the animal populations of which they were a subset.*' (O'Connor 2003: 194). A lack of consistency in both recording methods and the way in which lesions are classified inhibits the potential for obtaining comparable data.

2.7.1 Articulated remains

Although excavated in fewer numbers than human skeletons, articulated animal skeletons or associated bone groups (ABGs) have been recovered from archaeological sites, including Wetwang Slack (section 6.6.1) and Danebury Hillfort (section 6.6.3). However, they are rarely found in numbers (especially pathological examples) substantial enough to support population level analysis, something that

can occur on a regular basis in human palaeopathology. Peterson *et al.* (1982) conducted an osteological study of two wild moose populations that display the potential for zoopalaeopathology to explore palaeoepidemiology further under the correct circumstances. Although, the study was not conducted on archaeological material and the aim was to obtain measurement data, two specific types of pathological conditions were also noted in individual skeletons and between two populations. The approach taken and results display the successful incorporation of both a case-by-case and population approach to zoopalaeopathology. As a part of this research, the metatarsus, both halves of the mandible and the upper tooth rows were removed for analysis. Pathological conditions noted and compared between the two populations included, most notably, arthropathy and periodontal disease (Peterson *et al.* 1982: 2813-2815), not surprising considering the skeletal elements selected for analysis. Age and sex-related correlations with the frequencies of arthropathy and periodontal disease were also made, both on an inter and intra-population level. In zooarchaeology, the opportunity to study two securely dated populations of one particular species is an unlikely scenario; however, this study highlights the advantages of interpreting data at the population level using the skeletal remains of animals.

2.7.2 Disarticulated remains

However, in zooarchaeology, disarticulated assemblages are the norm and articulated skeletons the exception. Interpretation of pathological data on a population scale is problematic, but not impossible. Under these circumstances, prevalence as a measure of frequency could be applied either to those readily

identifiable localised pathological conditions affecting elements that are quantifiable or alternately, to a particular lesion type. The prevalence results would be crude and calculated against the 'Number of Identified Specimens' (NISP), but if conducted on a routine basis, the datasets generated would be most valuable and provide the means to explore further the frequency of different animal diseases in the past. However, consistency is vital if valid comparisons between datasets are to be made (O' Connor 2003: 195).

2.8 Conclusion

Zoopalaeopathology is described here as a developing field of study that requires the implementation of standardised guidelines and consistent recording protocols, and the wider dissemination of data. Until consistent recording and description of palaeopathological lesions is undertaken on a routine basis, the interpretation of disease in past animal populations will remain restricted to localised and gross pathological change and persistently described as being a sub-discipline in its 'infancy'. As Clark (1994: 10) astutely points out '*...the discipline has to acknowledge that it is adult*'.

3. BOVINE TUBERCULOSIS: A ZOONOTIC DISEASE

'*...the animal-specific pathogen, M. bovis, is arguably the most important zoonotic agent in human history.*'

(Abalos & Retamal 2004: 591)

3.1 Introduction

Zoonoses are infectious diseases that can be transmitted between humans and animals, both domestic and wild (Slingenbergh *et al.* 2004: 467). The phrase 'zoonosis' was first coined by Rudolf Virchow in 1855, when the link between animal and human health was observed through research on the parasitic round worm *Trichinella spiralis* (Schultz 2008: 1480-81). Cleaveland *et al.* (2001) compiled a database of pathogens known to cause disease in humans and domestic mammals. A total of 1415 pathogens were identified in humans, 616 in domestic livestock and 374 in domestic carnivores (Cleaveland *et al.* 2001: 993). Regarding domestic livestock, 39.4% of the 616 pathogens identified (n=243) also infected humans (Cleaveland *et al.* 2001: 995). Of the 1922 infectious pathogens recorded in the database, 17.1% (n=329) were associated with bacteria (Cleaveland *et al.* 2001: 993). Bovine tuberculosis (bTB) is a disease belonging to the genus *Mycobacterium.* It is '*...arguably the most important zoonotic agent in human history*' (Abalos & Retamal 2004: 591).

This chapter provides an overview of bTB; a disease with the ability to infect a wide-range of mammals and humans. In order to analyse the impact of bTB in past human and animal populations and to provide the means to identify it in zooarchaeological assemblages, it is essential to gain a thorough appreciation of the disease, its epidemiology and its pathogenesis in domestic livestock and humans. This chapter comprises three main parts: the first explores the *Mycobacterium tuberculosis* (MTB) complex, its evolutionary history, the epidemiology of *Mycobacterium bovis* (*M. bovis*) and the current status of the disease in humans in the present day. The second outlines the pathogenesis of this disease in domestic livestock (specifically cattle) and humans. This section also highlights the soft tissue lesions and skeletal lesions associated with the disease. Lastly, a brief literature review of bTB is presented. Evidence for its presence in the past is supported through historical sources and archaeological material.

3.2 *Mycobacterium tuberculosis* (MTB) complex

Tuberculosis belongs to the genus *Mycobacterium.* There are many different species of *mycobacteria* that possess the potential to cause illness in humans and other mammals. Tuberculosis (TB) and Leprosy are the two most prominent diseases associated with this genus (Roberts & Buikstra 2003: 4). Tuberculosis, in particular, consists of several different species that together form the *Mycobacterium tuberculosis* (MTB) complex. The *Mycobacterium tuberculosis* (MTB) complex comprises *Mycobacterium tuberculosis*, *M. bovis*, *M. canetti, M. africanum, M. microti, M. pinnipedii, M. caprae, and M. bovis* BCG (Somoskovi *et al.* 2007: 595;

Taylor *et al.* 2007: 153). There is also an avian strain, *M. avian,* belonging to the *Mycobacterium avian* (MAC) complex (Roberts & Buikstra 2003: 5-6).

3.3 A Disease of Considerable Antiquity

Until relatively recently, the general consensus (see Vincent & Gutierrez Perez 1999, Hershkovitz & Gopher 1999) was that *M. tuberculosis* evolved from *M. bovis* at the time of cattle domestication during the Neolithic period. This was a plausible hypothesis considering the newfound closeness of humans and animals at this point in time. However, contrary to this, it was demonstrated in research conducted by Brosch *et al.* (2002) that *M. tuberculosis* did not evolve from *M. bovis*; in fact, the two species evolved independently of each other from a common ancestor some 15-20,000 years ago (Brosch *et al.* 2002: 3688) (Figure 3.1). Therefore, *M. bovis* pre-dates the domestication of plants and animals and is consequently a disease of considerable antiquity.

Mycobacterium avian is predominantly pathogenic to birds (Feldman 1963: 5) but can also be contracted by humans (Roberts & Buikstra 2003:5) and other mammals, particularly swine (Feldman 1963: 5; Wight *et al.* 1942: 241). *Mycobacterium tuberculosis* primarily causes illness in humans and non-human primates in captivity (O'Reilly & Daborn 1995: 2), but has also been known to affect to a lesser extent cattle, dogs, parrots and swine (Feldman 1963: 5), the latter species largely affected as a by-product of contact (O'Reilly & Daborn 1995: 2). The highly adaptable nature of MTB complex and the wide host range of *M. bovis,* in particular, makes it a formidable disease and incredibly difficult to control (Feldman 1963: 5).

Mycobacterium bovis possesses *'one of the broadest host ranges of all known pathogens'* (O'Reilly & Daborn 1995: 1).

Figure 3.1 The Evolution of the *Mycobacterium tuberculosis* (MTB) complex displaying categorically that *M. tuberculosis* did not evolve from *M. bovis* (Brosch *et al.* 2002: Fig 2)

Cattle along with bison and buffalo are the natural hosts for *M. bovis* (Biet *et al.* 2005: 414), however, there are many different species of domestic and wild

mammal that can also act as maintenance hosts (reservoirs of infection) or non-maintenance hosts (spill-over cases) (Biet *et al.* 2005: 414). In maintenance hosts, as the term implies, infection can be maintained through horizontal transmission to other members of the same species and also any other susceptible species (Etter *et al.* 2006: 62; Biet *et al.* 2005: 414). However, infection in species described as non-maintenance hosts (spill-over cases) is intermittent and not normally maintained, unless there is a reservoir of infection present (Biet *et al.* 2005: 414). Humans represent spill-over hosts in relation to *M. bovis,* as highlighted in a study by Smith *et al.* (2004). In the United Kingdom, the badger (*Meles meles*) is a maintenance host and the red fox (*Vulpes vulpes*) is a spill-over host (see Figure 3.2). Specific examples of maintenance and non-maintenance hosts are illustrated in Figure 3.2. In South Africa, the lion (*Panthera leo*) is regarded as a spill-over host for *M. bovis* (section 3.9.1).

3.4 The role of wild animals

The role of wild animals in the maintenance and dissemination of *M. bovis*, particularly leading to infection and re-infection in domestic livestock, represents a substantial economic concern (Corner 2006: 303). In the early part of the 20th century, particularly the 1930s, newly reported cases of tuberculosis in humans in the UK numbered 50,000 per year. Of these, 2,500 were believed to be bovine in origin, due for the most part to the consumption of infected milk (Torgerson & Torgerson 2010: 67).

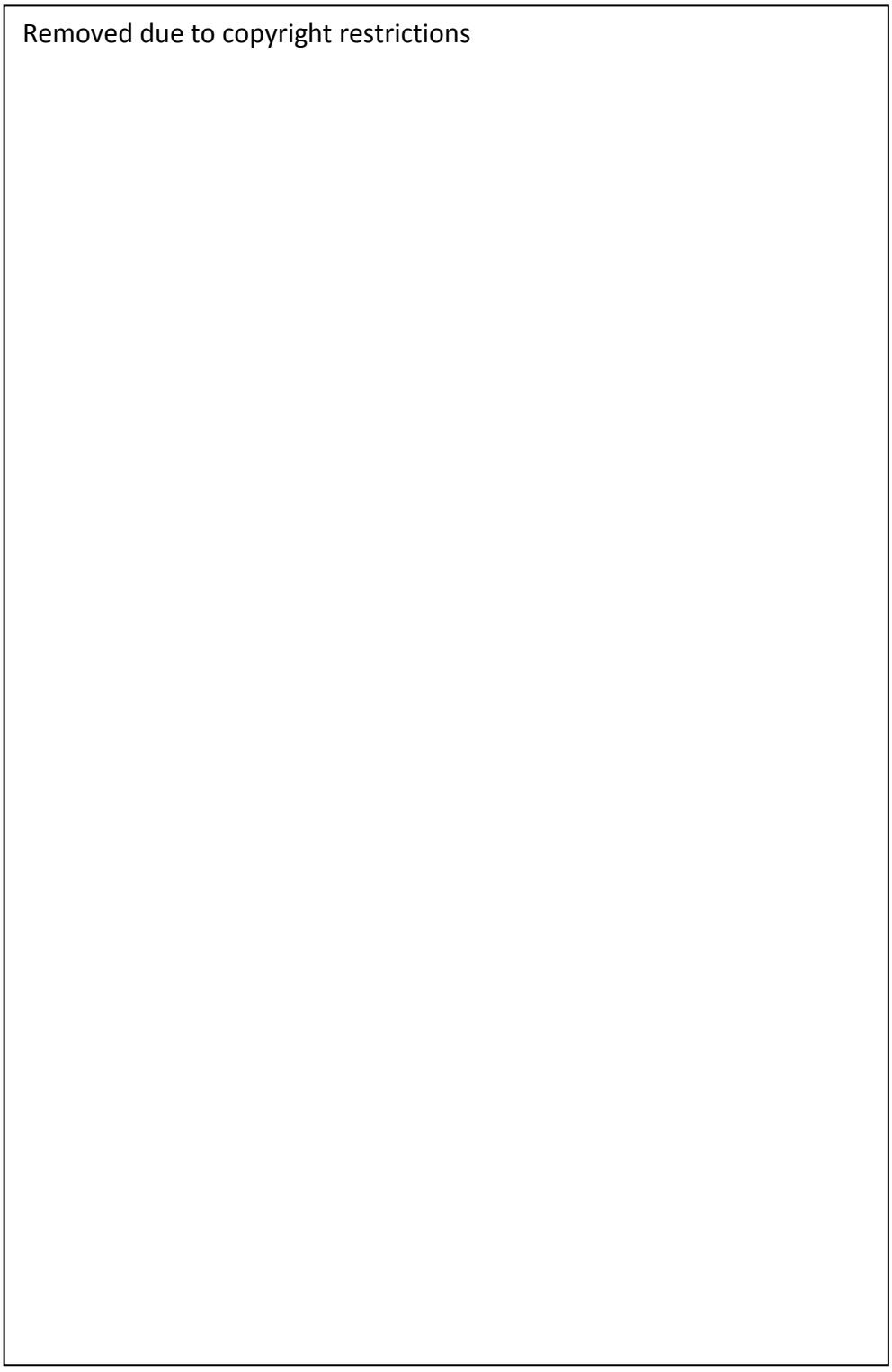

Figure 3.2 Examples of maintenance and non-maintenance hosts associated with *M. bovis* (Biet *et al.* 2005: Table 1).

The implementation of 'The Attested Herd Scheme for Cattle' in 1935 followed by the pasteurisation of milk in Great Britain led to a significant decrease in the number of cases reported in humans (Hardie & Watson 1992: 25). By the 1970s the disease had been eliminated from most areas of Great Britain (Torgerson & Torgerson 2010: 67). However, it was to re-emerge and is still an ever present problem for British farmers in the present day. In the United Kingdom, the number of herd breakdowns (new tuberculin positive cases in cattle) has steadily increased over the past fifteen years (Reynolds 2006: 120). In 2008, there was an increase of 18.9% reported in Great Britain, the majority in western England and Wales. In 2008, 37,012 cattle identified as reactors were slaughtered, representing an increase of 42% on the previous year (DEFRA 2008: 47). In 2009, this number slightly dropped to 34,765 (DEFRA 2009 – Appendix 1). Provisional figures for 2010 (Jan-April) again display a small decrease in the number of reactors slaughtered from 15,081 for the same period in 2009 to 11,708 in 2010 (DEFRA 2010 – Appendix 2). Badgers are implicated as the principal reservoirs of infection responsible for the continued re-infection of cattle herds and subsequent herd breakdowns in Great Britain (Neill *et al.* 2001: 79; O'Reilly & Daborn 1995: 37). As a result, a series of badger culls took place between 1973 - 1998 (ISG 2007: 19). In 1997, Prof. Krebs headed an independent scientific review group in order to evaluate further the incidence of *M. bovis* infection in cattle and badgers, in addition to investigating the links between the two species in terms of transmission. The results of the study indicated that badgers represented a considerable source of infection in cattle, but the extent of their input could not be measured (Reynolds 2006: 120). In 1998, the

independent Scientific Group on Cattle TB (ISG) was formed to further investigate this issue (Reynolds 2006: 120). The final report stated: '*On the basis of our careful review of all currently available evidence, we conclude that badger culling is unlikely to contribute positively to the control of cattle TB in Britain*' (ISG 2007: 172). As a result, in July of this year (2010), the Secretary of State announced that under new government policy in England, no licenses would be issued to cull badgers. As an alternative, an investment of £20 million over a period of three years has been made for research into vaccines for both cattle and badgers (DEFRA 2008: 48).

The majority of modern TB cases in humans are as a result of infection with *M. tuberculosis*. Infection with *M. bovis,* particularly in industrialized countries, is now largely deemed an occupational hazard (Moda *et. al.* 1996: 104) with isolated cases identified in farmers, veterinarians (see Fanning & Edwards 1991) and slaughter house/abattoir employees (O'Reilly & Daborn 1995: 18; van der Hoeden 1964: 3). In addition, people that are commonly in contact with infected soil or water may also be susceptible to infection in the present day, for example, sewerage and agricultural workers (van der Hoeden 1964: 4). It is impossible to distinguish which species of *mycobacteria* is responsible in clinical cases of TB (Moda *et al.* 1996: 103); therefore, it is difficult to gain a true idea of the prevalence of bTB in humans. However, infection with *M. bovis* has been demonstrated in a number of cases (Cosivi *et al.* 1998: 59), indicating that it is far more prevalent than most would anticipate. The number of people affected by bTB is undoubtedly higher in those countries of the developing world that possess little or no control measures concerning disease management of livestock along with no requirement by law to

pasteurize milk (Etter *et al.* 2006: 63). Although the risk of zoonotic infection in industrialized countries is perceived to be low, it is not inconceivable. In 1999, the health risk to humans posed by the zoonotic nature of *M. bovis* was highlighted with the first documented cases of 'indigenously acquired bovine tuberculosis' (Smith *et al.* 2004). Two siblings from the UK, both under the age of 25 years, were raised from childhood on the same farm. They were given the BCG vaccination at school, had never left the country and had not knowingly consumed unpasteurized milk, yet they were both found to be infected with bTB. One sibling had a history of limited contact with cattle on the family farm, and it is presumed that the original zoonotic transmission occurred as a result of this (Smith *et al.* 2004: 539). On two separate occasions, cattle in the herd were found to be tuberculin positive and slaughtered. Badgers caught in the local area were also found to be tuberculous upon post mortem investigation (Smith *et al.* 2004: 540). More recently, in 2005, an outbreak of bTB was reported on an Irish dairy farm. Unpasteurised milk was consumed from a seven-year-old cow with tuberculous mastitis (Doran *et al.* 2009: 393). Five of six family members tested positive when using the Mantoux test (Doran *et al.* 2009: 395); with the two youngest members of the family (7 years and 4 years of age) the most severely affected and requiring prolonged antibiotic treatment. The four-year-old presented with active tuberculosis and swelling of the cervical lymph nodes (Doran *et al.* 2009: 394). Torgerson & Torgerson (2010) recently criticised the allocation of funds in Great Britain for disease control associated with bTB, stating that in the present day with milk pasteurisation, the risk of zoonotic infection between humans and animals was 'negligible' (Torgerson & Torgerson 2010: 67). Torgerson & Torgerson make a fair point, if people are not

in constant contact with livestock and only consume pasteurised milk, then the risks associated with zoonotic infection are low. However, it is clear that there is still a tangible risk of contracting the disease from infected animals even in the present day. Alarmingly, Doran *et al.* (2009) report that even on working farms where the risks associated with zoonotic disease would seemingly be most apparent, a survey demonstrated that 84% of families associated with 230 suppliers of milk across eight counties in Ireland still consumed unpasteurised milk (see Buckley *et al.* 1998).

3.5 Tuberculosis: A global emergency

Tuberculosis had been considered by some in the recent past to be a conquered disease (Dormandy 1999: XIV). The introductory sentence of an article written in 1981 illustrates this by stating: '*This is a chronicle of the conquest of tuberculosis*' (Warring 1981: 177). Unfortunately, this infectious pathogen is highly adaptive and opportunistic. Poverty in developing countries and the rise of the Human Immunodeficiency Virus (HIV) enabled the disease to prey upon the ill, weak, malnourished and immuno-compromised with devastating effect. The association between HIV and TB infection has been coined by some as '*An Alliance of Terror*' (Ryan 1992: 385-405). In modern times, the control of TB has been greatly impeded not only by the emergence and spread of HIV but also by population growth (WHO 2008a: 1). In 2008, 9.4 million incident cases of TB were estimated globally (Figure 3.3). Of these, between 1.2-1.6 million were estimated to be HIV positive (Figure 3.4) (WHO 2009a:4).

Figure 3.3 Estimated global incidence of TB in 2008 (WHO 2009a: Figure 1)

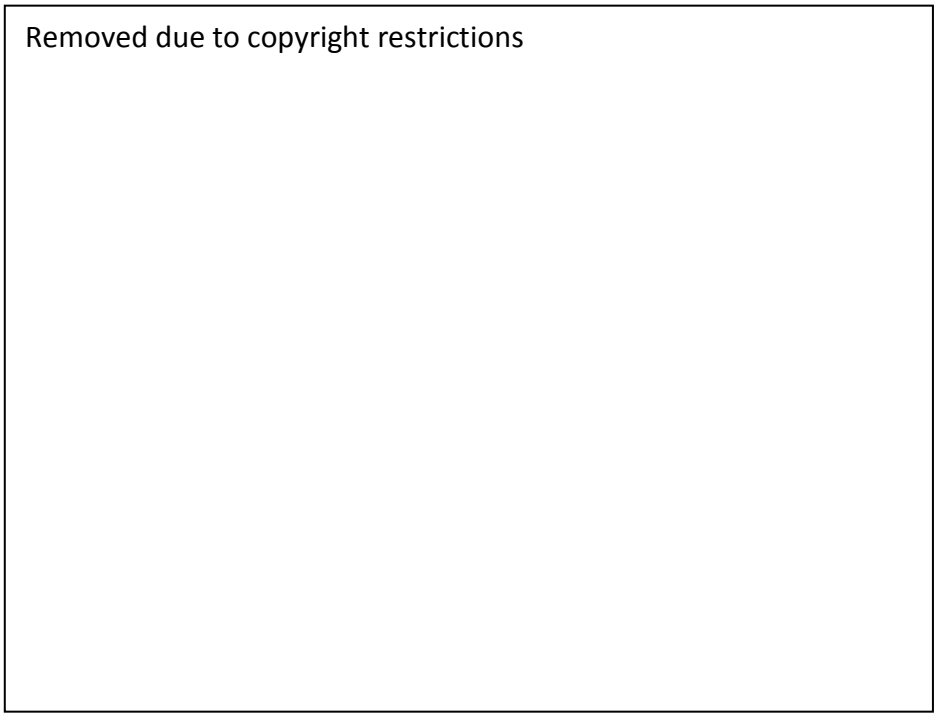

Figure 3.4 Estimated global HIV prevalence associated with new TB incident cases in 2008 (WHO 2009a: Figure 2)

Described as a 'disease of poverty' in present times (WHO 2009b), those areas most severely affected are predictably the poorer countries within the developing world, most notably in Africa and Asia (see Figure 3.3) (WHO 2009a: 4). Providing adequate and sustainable aid to those in dire need has proved challenging and ultimately unsuccessful, resulting in the evolution of both a 'multi-drug resistant' strain (MDR-TB) and an 'extensively drug resistant' strain (XDR-TB) (WHO 2008). In 2008, 1.8 million people succumbed to this disease. This included 500,000 who were also suffering from HIV, resulting in 4,500 deaths per day (WHO 2009b). This statistic is especially disturbing in light of the fact that TB is largely preventable by vaccination (BCG) and curable by antibiotic treatment.

3.6 The pathogenesis of bTB in domestic animals with specific reference to cattle

The majority of the information available concerning the pathogenesis of TB has largely been collected through the anatomical study of human remains (Francis 1947: 63). As a result, the disease process in humans is understood to a greater degree than its pathogenesis in animals (Neill *et al.* 2001: 79). The wide host-range of the latter and species-specific differences represents a possible contributory factor (Cohrs 1967: 124). The following section outlines in detail the pathogenesis of bTB in cattle, the natural host of the pathogen. Cohrs (1967) defines four main stages associated with the pathogenesis of bTB in cattle. These stages are outlined below and also illustrated in Figure 3.8. This is supplemented with information related to the disease in other mammal species, including sheep, goat, pig, horse, dog and cat. Significant differences are highlighted. Horses, sheep and goats are

largely resistant to *M. bovis* infection (Wight 1942: 241). The pathogenesis of the disease in cattle has been noted as being 'similar' to the disease in humans (Cohrs 1967). The pathogenesis of the disease in humans is outlined in section 3.11.

The pathogenesis of any disease is a complicated process influenced by a number of factors, both intrinsic and extrinsic, to the animal host. For example, immune status and hereditary resistance can form pre-determining factors, whereas specific breed is not thought to be especially pertinent (Cohrs 1967: 128-9). The degree of exposure is an important factor and is intimately associated with the immune status and level of resistance (Wight *et al.* 1942: 242). Environmental conditions, diet, animal husbandry, other diseases and increased stress through travel (section 5.5.4) or lactation are important external factors that may impact upon the way the disease progresses (Cohrs 1967: 127-8). An example of animal husbandry affecting the likelihood of disease is the process of fattening pigs. Weight gain is rapid over a short period of time, providing a distraction from disease resistance. In one example, it is cited that on average 150-300 pounds of weight is gained over a period of 8-10 months (Mohler & Washburn 1923: 12).

3.6.1 Stage 1 & 2: Primary Infection with the possibility of Re-infection/Reactivation

This initial stage in the disease process forms the entry and establishment of the tubercle bacilli within the tissue of the host. The affected tissue is inflamed and exudative; a combination of Langhans giant cells and endothelioid cells encapsulates the affected area, which in turn is reinforced by lymphocytes. This

comprises the ‘primary focus’, within it the bacilli multiple and are transported by the lymph to associated lymph nodes within the vicinity of the focus (Figure 3.5). The development of the primary focus and the involvement of the lymph nodes signify the establishment of the ‘primary complex’ (Francis 1947: 63; Nieberle and Cohrs 1967:124). Lymph nodes located in the throat represent the first opportunity for lymph node involvement, followed by the mesenteric lymph nodes in the intestine (Wight 1942:239).

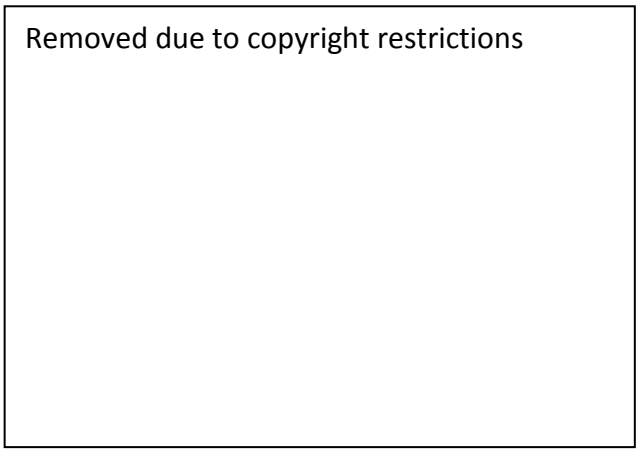

Figure 3.5 Infected cattle lymph node displaying primary caseation (Cohrs 1967: Fig 71)

The location of the primary infection is often within the lungs (Figure 3.6) or the digestive tract (Figure 3.7), depending upon the route of infection (Cohrs 1967: 125). Results obtained from numerous meat inspections indicates that lesions in the thoracic region are more frequently observed than lesions in abdominal region in cattle (Francis 1958: 21). In cattle and older calves, the lungs are the most frequent location, followed to a lesser degree by the digestive tract. This is also the case in younger calves; however, the liver is also a focal point for infection as a result of congenitally acquired tuberculosis with a small proportion of calves also prone to

developing infection in the digestive tract due to the consumption of infected milk. The lungs also form the most prominent focus for infection in goats and sheep, whereas horses, poultry (namely hens) and pigs favour the digestive tract (Francis 1958: 21). In pigs, the glands and tissues associated with the digestive tract are most often involved, followed by the glands in the throat (Mohler & Washburn 1923: 12). The lungs and digestive tract appear more equally affected in cats and dogs (Cohrs 1967: 125), although the lung appears favoured in the dog and the intestines in the cat (Snider 1971: 881). The mammary glands, genital tract and even in some cases the eyes (specifically in cats) can also form the location of the primary infection (Cohrs 1967: 125). The environment of the animal plays an extremely influential role in the manner by which the disease is contracted as Belschner (1967) emphasises. For example, dairy cows housed indoors are predisposed to contracting tuberculosis via the respiratory route and developing primary infection in the lungs. Whereas those animals kept outdoors on a regular basis may be more prone to alimentary infection with a focus developing in the digestive tract (Belschner 1967: 56). Pigs, for example, have been documented as contracting bTB from infected cattle through the ingestion of unpasteurised milk and dairy products and the practice of allowing them to accompany cattle in the feeding area, whereby they consume undigested grains from the cattle dung (Mohler & Washburn 1923:3). Cats and dogs are more evenly proportioned with both the lungs and digestive tract affected equally. This is probably because they can live both indoors and out (Cohrs 1967: 125).

Figure 3.6 Primary focus located in the main lobe of a bovine lung. There is also lymph node enlargement (Cohrs 1967: Fig 175, with additions)

Figure 3.7 Tuberculosis of the intestine in a cow, displaying ulcerative lesions (Nieberle and Cohrs 1967: Fig 321)

Upon establishment of the primary complex, there are three options for possible disease progression dependent upon the host's general health, stress level, immune status, nutrition and environment. Firstly, the primary focus may heal leaving behind only scar tissue and an animal with greater resistance to re-infection. Secondly, the primary focus and the tubercle bacilli within it, although still infective, may become dormant and inactive for a time, maintaining a status quo. However, this could be undermined by a change in the animal's immediate circumstances leading to re-activation (Cohrs 1967: 124). Finally, the host's attempt to halt the disease may prove ineffectual with the disease progressing relatively quickly and spreading to other parts of the body (other organ systems and the skeletal system) via dissemination otherwise known as 'early generalisation' (Cohrs 1967: 125).

Early generalisation can progress in a variety of ways based upon the rate of dissemination and the immune reaction of the host. The initial spread of the tubercle bacilli is achieved via transport through the circulatory and lymphatic systems providing access to organs, lymph nodes and the skeletal system (Cohrs 1967: 128-9). If the generalisation is widespread at this stage with many new tuberculous focuses established, 'acute generalisation' has occurred. However, if the tubercle bacillus is less virulent and aggressive in its early dissemination and tuberculous focuses are created over a longer period of time then 'protracted generalisation' has occurred. Although both forms have been identified in a variety of domestic animals, protracted generalisation is most often the observed end result in horses and pigs (Cohrs 1967: 128-9). In the majority of cases, the end result of either acute or protracted generalisation is miliary tuberculosis, followed quickly

by death. However, there are a number of animals that may not succumb to death, perhaps as the result of a change in surroundings, living conditions or a more nutritious diet. This is often observed in pigs and cattle, whereby the primary focuses will either heal or become inactive as mentioned earlier, thus creating the possibility of the cycle already described being repeated through either re-infection or reactivation of an already established but dormant primary complex (Cohrs 1967: 126).

3.6.2 Stage 3: Post Primary Period

Upon re-infection or reactivation of a primary complex, the 'post primary period' occurs. This stage within the disease process is the most commonly observed in cattle and humans (Cohrs 1967: 127). It is less frequent in other domestic animals, but may be seen in older breeding pigs, dogs and goats. This is not unlike the initial primary infection stage, but there are a number of differences concerning the subsequent progress of the disease. The lymphatic and circulatory system are no longer involved in the dissemination of the infective tubercle bacilli. This is instead accomplished, by amongst others, the bronchi in the lungs. In addition to this, the lesions are not subject to calcification, remaining instead soft with the potential to rupture and cause further infection. The final difference is that unlike the primary infection stage, there is no lymph node involvement. Due to these differences, there exists little means for widespread dissemination; therefore, the tubercle bacilli are instead restricted to infiltrating either a single organ or a specific system of organs. This is referred to as 'isolated organ tuberculosis' and, as this stage within the disease process is relatively slow in its advancement, it progresses on to

'chronic organ tuberculosis'. There is the remote possibility that the affected organ may heal, but any additional stress will render the host defenceless and the final 'breakdown' stage is initiated (Cohrs 1967: 127).

3.6.3 Stage 4: Breakdown

Resistance acquired by the host throughout the previous stages of this disease process, if compromised at this stage inevitably leads to the 'breakdown' phase - the final stage within the pathogenesis of bTB (Cohrs 1967: 127-8). Upon commencement of this stage, a number of primary focuses are again formed that have the potential to increase in size. In addition to this, the lymphatic and circulatory systems are once again involved resulting in widespread dissemination of bacilli. The use of the lymphatic system ensures that the lymph nodes are affected. This pattern of disease progress mirrors that of 'early generalisation' featured within stage one. However, since this destructive and highly widespread dissemination occurs during this later breakdown stage, it is referred to as 'late generalisation' and results in death (Cohrs 1967: 128).

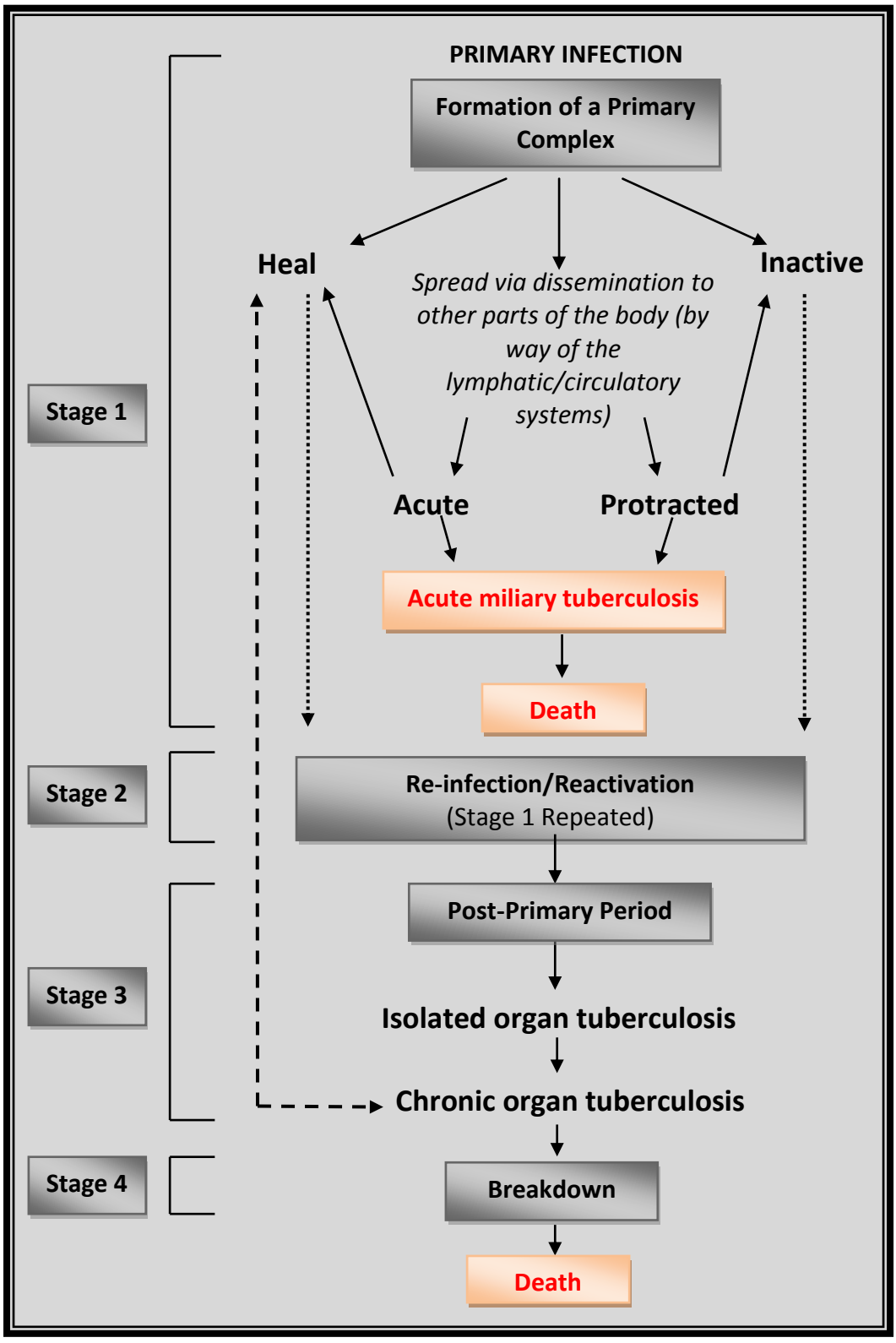

Figure 3.8 The Pathogenesis of bTB in cattle (based upon the information from Cohrs (1967)

3.7 The symptoms of bTB in domestic animals with reference to cattle and pig

By comparison with other bacilli, the tubercle bacilli are relatively inactive. The initial process of multiplication takes the tubercle bacilli on average one day, whereas the same process takes roughly 30 minutes for the typhoid bacilli (Burnet & White 1972: 213). The period of incubation varies for different animal species and humans (Wight 1942: 240), but generally speaking, symptoms are slow to manifest in infected humans and animals (Burnet & White 1972: 213). Therefore, an animal could be suffering from bTB for a considerable amount of time before any symptoms manifest (Wight 1942: 240; Belschner 1967: 57). Some animals may even appear to be in good health when they are in fact heavily infected, as Wight (1942: 240) highlighted, '*...cattle that appear to be in prime condition may be grossly tuberculous...*' This is an important point for discussion in relation to the presence and identification of diseased animals in the past. Even when overt symptoms are apparent, it can prove challenging to differentiate them from other potential illnesses (Belschner 1967: 57). However, there are a few characteristic signs that are potentially symptomatic of tuberculosis.

3.7.1 Weight loss

In both cattle and older pigs with progressive disease, there may be a gradual but substantial weight loss leading to an emaciated appearance. In cattle, the coat becomes dull in appearance and rough to the touch. There is a general unthriftiness in the general countenance of the animal (Belschner 1967: 57; Wight 1942: 240; Haring 1913: 1).

3.7.2 Cough

In cattle suffering from pulmonary infection, there may be a dry cough, most noticeable upon exertion. This may get progressively worse and more persistent as the infection progresses (Belschner 1967: 57). In pigs with pulmonary infection, there is a continual dry cough, which worsens upon increased activity. This cough is, however, indistinguishable from that associated with a lungworm infection (Mohler & Washburn 1923: 10).

3.7.3 Enlarged lymph glands

There may be enlargement of the superficial glands in all parts of the body, but particularly the head, neck, thorax, abdominal, udder and genital region. As the tubercle bacilli infiltrate the lymphatic glands in the early stages of the disease, these may display enlargement before any other symptoms are manifest (Belschner 1967: 57). Enlargements in the throat in cattle may cause difficulty in breathing and result in snoring and the positioning of the head horizontal to the body (Haring 1913: 2; Belschner 1967: 58). A rare side effect of enlarged glands in the chest region of cattle is bloating. This may transpire as a result of the swollen glands obstructing the passage of gas (Belschner 1967: 58).

3.7.4 Disease of the udder

If the cattle udder is affected, small hard nodules or lumps may be felt upon examination of the region, these are especially obvious after milking but are not hot to the touch or obviously painful (Haring 1913: 2; Belschner 1967: 58).

3.7.5 Diarrhoea

If the intestines and, in particular, the bowels are affected by the disease in cattle, diarrhoea may result (Haring 1913: 2). In pigs, constipation or diarrhoea may result from disease in the intestinal region (Mohler & Washburn 1923: 10).

3.8 Skeletal Lesions in domestic animals with reference to cattle and pig

There is an unfortunate dearth of information concerning the morphology of tuberculous skeletal lesions in animals, both domestic and wild, a fact highlighted by several authors in the literature (see Lignereux & Peters 1999; Roberts & Buikstra 2003 and Mays 2005). There is also a regrettable lack of skeletal reference material associated with known tuberculous animals from which to compare, contrast and differentially diagnose. This is unsurprising considering modern day control measures and the slaughter of tuberculin reactors in the UK. Therefore, apart from isolated modern cases, the majority of information related to skeletal TB was compiled during the pre-tuberculin era. There are a small quantity of illustrations originally published in the early 20th century German veterinary textbooks displaying skeletal lesions affecting both cattle and pig. In addition to this, there is a single image of a tuberculous cattle rib published more recently in 1967. Although limited in number, these serve as extremely informative depictions of osseous lesions associated with animals suffering from TB (Figures 3.9-3.13). Skeletal lesions are reportedly more frequent in pigs and cattle; published figures indicate that 8-9.5% of pigs with MTB complex display skeletal lesions and 0.5-1% in cattle. By contrast, tuberculous skeletal lesions are identified in 90-93.5% of cases in fowls (Cohrs 1967: 855). In light of these statistics and using information provided by

several texts, the lesion distribution of bTB in cattle and pigs was compiled (see section 8.3).

3.8.1 Cattle rib (i)

Figure 3.9 is a cattle rib displaying a proliferative focus on the body of the rib. The area of swelling is porous and hollow. The interior appears to possibly consist of smooth margins and would have contained a purulent exudate, representing an osteomyelitis. There also appears to be some minor pitting around the margins of the lesion. The rest of the rib appears unaltered apart from the slight enlargement of a foramen just distal to the main lesion. In the literature, this bony outgrowth is differentiated from a fracture callus via the morphology of the cortex – if it is fragile and thin, it is more likely to be associated to an aetiology other than trauma (Lignereux & Peters 1999: 343).

Figure 3.9 Cattle rib displaying proliferative bone formation/porous swelling with an area of bone lysis at the centre (Kitt 1905: Fig 198).

3.8.2 Cattle rib (ii)

This cattle rib appears to have been partially sliced in half at the distal end to display the morphology of the lesions and their effect on the skeletal structure of the rib. There are multiple focuses (tubercles) that have infiltrated the bone marrow leaving irregularly shaped space-occupying lesions. These have been referred to as 'cold fistulized abscesses' (Lignereux & Peters 1999: 342). Although there is no other view of this rib provided, it is presumed that it was swollen in appearance. By contrast to Figure 3.9, this cattle rib would appear to be solely osteolytic, although it also appears osteitic.

Figure 3.10 Cattle rib displaying multiple irregularly shaped osteolytic lesions caused by multiple small tubercles (Kitt 1905: Fig 199).

3.8.3 Cattle rib (iii)

This cattle rib displays a prominent proliferation of compact new bone. The ossified new bone growth is irregular in shape, porous and possesses numerous cavities that would have contained a caseous exudate. This lesion is an example of a periosteal response to infection, whereby a number of bony projections (osteophytes) have formed. This has then become infiltrated with the disease process resulting in a number of cavities forming. The condition is termed *spina ventosa* (Cohrs 1967: 856).

Figure 3.11 Tuberculosis of a bovine rib (*spina ventosa*) (Cohrs 1967: 639)

3.8.4 Cattle scapula

Figure 3.12 is a cattle scapula displaying multiple osteolytic lesions on the lateral and dorsal face of the blade. The glenoid fossa, neck and distal portions of the blade are unaffected. The lesions are relatively shallow and do not perforate through the associated blade completely. The lesions are irregular in shape and resemble the osseous response associated with miliary tuberculosis.

Figure 3.12 Cattle scapula displaying multiple, irregular osteolytic lesions on the lateral surface of the blade (Kitt 1905: 197).

3.8.5 Pig thoracic vertebrae

Figure 3.13 is an illustration of a longitudinal slice through a pig thoracic vertebral column displaying three articulated vertebrae. There are two primary pathological lesions. The first is associated with the most caudal thoracic vertebral body. Within the body, there are 2-3 lesions present. As this specimen is macerated, the visible lesions appear to be abscesses, possibly associated with osteomyelitis. There is no way of knowing if the lesions had perforated the cortical bone forming cloacae to drain any purulent exudate. The second lesion is labelled a, b and c on the illustration and consists of a large swelling located just dorsal to the neural arch, predominantly affecting the thoracic spine. This large swelling is another abscess which has completely consumed the mid-portion of the spinous process. The swelling has also encroached both cranially and caudally, with the latter the most extreme. The occurrence of similar destructive focuses in the region of the neural arch and spinous process in humans is rare (Ortner 2003: 231). Therefore, this illustration potentially highlights a crucial difference in the way in which tuberculous foci manifests itself in pigs.

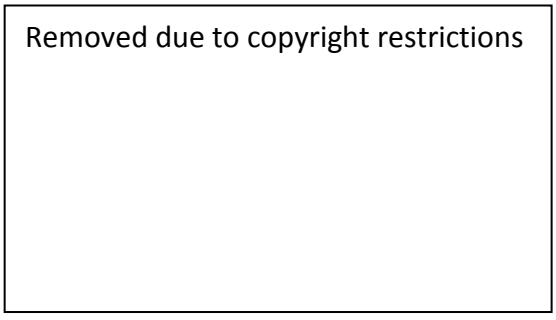

Figure 3.13 Pig thoracic vertebral column displaying the presence lesions within the vertebral body and also a large swelling within the spinous process (Ostertag 1922: 602 cited in Lignereux and Peters 1999: fig. 6)

According To Lignereux and Peters (1999: 342-3), the morphology of osseous lesions in animals suffering from TB predominantly comprise 'cold fistulized abscesses' (Lignereux & Peters 1999: 342-3). The preference for the tubercle bacilli to localise in areas rich in haemopoietic marrow, namely the cancellous bone associated with the vertebral bodies, metaphyses and epiphyses of the long bones results in the disease often presenting itself as *'tuberculous osteomyelitis'* (Cohrs 1967: 855). Tuberculous arthritis can also occur as result of infection, the latter especially a feature when the joints are targeted (Lignereux & Peters 1999: 342-3). Inflammation of the joints is a symptom often reported in tuberculous pigs (Wight 1942). Tuberculosis is largely destructive, however, in animals there is a tendency for new bone formation to occur as either reactive or reparative in nature. Periostosis is not a direct feature of this disease, but periosteal irritation in response to the development of a fistula in the bone can result in reactive new bone formation (Cohrs 1967: 856). In addition, the periosteum in those areas affected by disease may initiate a reparative response through the formation of osteophytes. If the tuberculous focus extends into these new bone protrusions, multiple cavities are formed resulting in a condition called *spina ventosa* (Figure 3.11) (Cohrs 1967: 856). This condition is not pathognomonic of bTB in animals but presents one of the ways in which the periosteum may react to this disease. This type of osseous response is, in fact, more commonly observed in animals suffering from actinomycosis (see section 4.2.2) (Cohrs 1967: 856). In addition to those bones that are highly cancellous, bones that are also located in close proximity to lymph nodes also provide potential sites for skeletal lesions as a result of direct transfer. Infected lymph nodes may rupture resulting in the infiltration of the surrounding tissues with

bacilli (Cohrs 1967: 855). Examples include: the intercostal and thoracic aortic lymph nodes located close to the thoracic vertebrae and rib heads and the cranial sternal lymph nodes located dorsal to the manubrium (Figure 3.14).

Figure 3.14 Location of the intercostal and thoracic aortic lymph nodes and the cranial sternal lymph nodes in cattle (Dyce *et al.* 1996: fig. 27-9, with additions)

3.9 Case Studies: Skeletal TB in domestic and wild animals

The following three case studies present examples of confirmed skeletal TB. The lesions observed in a wild animal (section 3.9.1) and two domestic animals (sections 3.9.2 & 3.9.3) are presented illustrating morphological diversity that aids in the better understanding of species-specific differences.

3.9.1 Lion (*Leo pantera*), Kruger National Park, Mpumalanga Province, South Africa

Bovine tuberculosis was first identified in the African buffalo population at Kruger National Park (KNP), South Africa, in 1990. The disease was introduced into the wild buffalo population by domestic cattle between the 1960's and 1980's (Rodwell *et al.* 2001: 258). In 1999, the prevalence of bTB in the buffalo was reportedly in excess of 70%, with other wild species, including lion, cheetah and baboons also infected as spill-over hosts (Weyer *et al.* 1999: 1113). Dr. Roy Bengis, Chief State Veterinarian at KNP kindly provided images of a number of pathological skeletal elements from a lion with confirmed *M. bovis* (Figures 3.15-3.18). *Mycobacterium bovis* is cultured from the lesions (illustrated below) on a regular basis, as well as from synovial structures displaying inflammation (Bengis pers. comm.). Although these images are of a wild animal, they are still informative and illustrate the morphology of skeletal lesions associated with felids confirmed as being infected with *M. bovis*.

Figure 3.15 Caudal aspect of a distal femur displaying exuberant spicules of new bone affecting the distal diaphysis. The joint surface is not involved (Photo: Dr. R. Bengis)

Figure 3.16 Proximal tibia and fibula displaying exuberant proliferative new bone affecting the proximal diaphysis of the tibia and also the interosseous space between the tibia and fibula (Photo: Dr. R. Bengis)

Figure 3.17 Calcaneus (tuber calcis) displaying compact but irregular new bone proliferation along the diaphysis (Photo: Dr. R. Bengis)

Figure 3.18 Scapula and humerus displaying new bone formation around the joint articulation, specifically affecting the proximal humeral neck and the neck of the scapula (Photo: Dr. R. Bengis)

The distribution of the lesions indicates that the appendicular skeleton is favoured, although the vertebrae are also involved in some cases. The actual joint surfaces, in Figure 3.18 appear unaffected, with a periosteal response affecting the joint margins. One of the symptoms of the disease in lions is swollen joints (de Lisle *et al.* 2002: 318).

3.9.2 Dog, Ontario, Canada

A pathological dog skeleton was excavated from a 16th century Neutral Iroquoian site located in Ontario, Canada. The dog was a male and no more than 3 years of age at death (Bathurst & Barta 2004: 918). The osseous lesions were consistent with hypertrophic osteopathy (HPO). This disease is progressive and characterised by symmetrical periosteal lesions affecting the appendicular skeleton. The joints are not involved (Bathurst & Barta 2004: 918). The lower fore and hind limbs were affected in this case, with the metapodia displaying the most severe lesions (Figures 3.19-3.20). Ancient DNA (aDNA) analysis identified MTB complex DNA indicating that the HPO was secondary to a primary TB infection. The association between HPO and TB in dogs and cats has been noted elsewhere (see Snider 1971: 880).

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Figure 3.19 The metacarpals displaying exuberant proliferative new bone formation on the diaphyses (Bathurst & Barta 2004: Fig 4)

Figure 3.20 Proliferative new bone formation on the metatarsals and calcaneus. The joint surfaces are unaffected (Bathurst & Barta 2004: Fig 5)

3.9.3 Horse, UK

This case study details the skeletal lesions associated with a six-year-old gelding admitted to the University College Veterinary Hospital with a stiff neck and general lethargy (Kelly *et al.* 1972: 59). *Mycobacterium bovis* was confirmed as the underlying cause of the illness. Vertebral osteomyelitis was observed in the bodies and spinous processes of the cervical vertebrae (C2, C4, and C5) and the spinous process of a thoracic vertebra (T4) (Kelly *et al.* 1972: 65-67). Multiple osteolytic lesions were identified in the spinous process of C2 with radiographs indicated that the margins of these lesions were sclerotic. New bone proliferation was observed on the dorsal surfaces of C4 and C5. A combination of osteolytic lesions and new bone proliferation affected the spinous process of T4, resulting in a swollen, enlarged appearance (Figure 3.21) (Kelly *et al.* 1972: 61).

Figure 3.21 Thoracic spinous process displaying osteolytic lesions (red) and bone proliferation leading to enlargement/swelling (blue) (Kelly *et al.* 1972: fig 4)

The first two sternal segments (sternabrae) were also noted as being swollen, with new bone proliferation and osteolytic lesions in the cancellous bone. A swelling was also identified on the head of a rib; it consisted of an osseous exterior but contained granulomatous material (Kelly *et al.* 1972: 62). Unfortunately, all the images published in the original article were of a poor resolution upon photocopying and only Figure 3.21 was able to be used. However, the description of the lesions and their distribution are extremely informative. The association between bTB in horses and vertebral osteomyelitis, particularly associated with the cervical vertebrae, has been reported in the literature for some time (see Collins *et al.* 1971; Markel *et al.* 1986). However, prior to the study by Kelly *et al.* (1972), there was caution and scepticism concerning the specific aetiology of these lesions and whether they could be directly associated with bTB or not. However, the successful extraction of acid-fast bacilli directly from the vertebral lesions by Kelly *et al.* (1972) led them to conclude: '*Our success in demonstrating tubercle bacilli in granulomatous cervical osteomyelitic lesions in a typical case of equine tuberculosis fills a gap in the literature and establishes more conclusively than heretofore that cervical vertebral lesions in affected horses may be tubercular in origin.*' (Kelly *et al.* 1972: 66).

3.10 Case Studies: Interpretation and Summary

The skeletal lesions associated with the lion and dog case studies displayed a different morphology to that described for other species, specifically ruminant species, pigs and humans. The lesions associated with the lion are striking in their overall morphology. The emphasis as indicated by these images appears to be bone proliferation over bone lysis. The bone proliferation is exuberant and disorganised

with some examples resembling the 'starburst' hypertrophic response often seen in malignant neoplasms (section 4.5). This case is interesting and although it is in isolation, if representative, indicates that felids or carnivores, in general, with *M. bovis* may exhibit a largely hypertrophic response to infection. This is especially relevant in light of the tendency for dogs to develop hypertrophic osteopathy (HPO) in association with a primary TB infection (section 3.9.2). As Snider (1971: 881) states, '*The primary focus of tuberculosis in the dog and cat presents a cellular productive character in contrast to the necrotic character of human and bovine lesions.*' Although the lesions illustrated in section 3.9.2 are not directly associated with skeletal TB, the link between HPO and TB infection in dogs and cats and the characteristic lesions associated with HPO means that the latter could potentially comprise a target disease for the search and potential identification of MTB complex infection in archaeological faunal assemblages. The lesions observed in the horse skeleton are very informative as they provide comparative data related to lesion morphology and lesion distribution in one of the domestic species regularly found as ABGs in the Iron Age. In addition, a pathological horse skeleton at Wetwang Slack, East Yorkshire, displayed very similar lesions (section 10.4.1). This modern case study directly linked bTB with osteomyelitis in the cervical vertebrae. The identification of lesion specificity in relation to aetiology is a subject that is still hotly debated, especially since the more frequent contribution of biomolecular methods such as aDNA analysis and mycolic acids analysis to palaeopathology.

3.11 The Pathogenesis of bTB in humans

The pathogenesis of *M. tuberculosis* in humans is well documented (see Ortner 2003; Aufderheide & Rodriguez-Martin 1998; Garay 1996; Jagirdar & Zagzag 1996; Jaffe 1972). However, there is less information available concerning the specific pathogenesis of *M. bovis*. The reason for this would appear to lie in the difficulties in differentiating the bovine disease from the human disease when it manifests clinically. It is reported in the literature that bTB *in humans* is '*indistinguishable with regard to pathogenesis, lesions and clinical findings to that caused by M. tuberculosis.*' (Moda *et al.* 1996: 103). Therefore, the following section briefly outlines the general pathogenesis of MTB complex in humans, with particular reference to those skeletal lesions that may indicate a bovine origin. As with animals, numerous intrinsic and extrinsic factors possess the potential to influence the pathogenesis of the disease in any human host, including: sex, age, immunology, living and working conditions, nutrition and population density (Kiple 2003: 337).

In humans, tuberculosis is often described as 'bi-phasic' consisting of two main phases: a primary infection phase and a secondary re-infection/reactivation phase (Figure 3.22) (Aufderheide and Rodriguez-martin 1998:119). The primary complex is established when a focus has established itself in the lung in addition to lymph node involvement – this is referred to as the '*Ghon complex*' after Anton Ghon an Austrian pathologist (Jagirdar & Zagzag 1996:467).

Figure 3.22 The pathogenesis of TB in humans (Roberts & Buikstra 2003: Fig. 1.4, with additions)

The factors that influence whether or not a primary infection of the lungs or indeed the intestines/digestive tract progresses to involve the skeleton are as follows (Ortner & Putschar1985:141):

1) Size of the innoculum

2) Virulence of the organism

3) Resistance of the host

In the majority of cases in humans, the primary infection heals with no further disease progression (Ortner 2003: 227), often asymptomatic and leaving little trace of the infection (Aufderheide & Rodriguez-Martin 1998: 119). This is in direct contrast to primary infection in cattle, which invariably results in progressive disease (Collins & Grange 1983:24). In humans, it is the second stage of re-infection/reactivation that involves haematogenous dissemination and involvement

of other organs and the skeleton (Ortner 2003: 227). Skeletal infection in humans is achieved via dissemination through the vascular system. The arteries generally provide passage for the bacilli around the skeletal system, although in some instances in the axial skeleton, Batson's plexus of veins are also utilised (Tuli 2004: 9).

Whereas, *M. tuberculosis* infection is not especially virulent in cattle, the opposite is true for human sufferers with *M. bovis.* Infection with *M. bovis* may be either aerogenous or alimentary in humans leading to primary infection in the lungs or, alternatively, the intestines and mesenteric lymph nodes (Roberts & Buikstra 2003: 19). Prior to the pasteurisation of milk and less stringent control measures, human infection with *M. bovis* was primarily through ingestion of contaminated milk products and the resulting infection and clinical lesions were extra-pulmonary (Grange 1995: 35). A total of 35% of extra-pulmonary infections in 1932 were associated with *M. bovis* (Grange 1995: 35). In addition, in 1937, it was reported that *M. bovis* was responsible for 85% abdominal TB, 50% cervical lymphadenitis (scrofula), 49% lupus, 25% meningitis and 20% bone and joint TB in Great Britain. It must be highlighted that gastro-intestinal infection can also be initiated through the swallowing of infected sputum, secondary to a primary pulmonary infection or, the result of haematogenous dissemination (Lewis & Field 1996: 587). However, it is clear that *M. bovis* was the progenitor of human infection in higher numbers than was perhaps assumed in the early 20th century.

Pulmonary infection due to *M. bovis* was initially thought to be rare, but cases have been identified with a greater prevalence recorded in rural areas in the past. These rural cases were deemed to be mostly associated with aerogenous infection as illustrated by the infection of a 19-year-old dairy maid. This individual was infected with bovine tuberculous; the focus was located within the lung with additional mesenteric lymph node involvement (Grange 1996: 36).

3.12 Skeletal Lesions in humans with reference to *M. bovis*

The skeletal lesions associated with TB in humans, as reported in the medical and human palaeopathological literature, are predominantly destructive/osteolytic comprising both bone resorption and bone lysis (Ortner 2003: 230). There is little new bone proliferation or bone regeneration associated with the disease in humans (Mays 2005: 130). This comprises a substantial difference to the disease as it manifests in animals. Reactive and reparative new bone proliferation is a prominent feature, specifically in ruminant species and pigs, as evidenced in Figures 3.9-3.13. This also appears to be a specific feature in wild felids (section 3.9.1). Those bones rich in haemopoietic marrow, including most frequently the long bone metaphyses, epiphyses and vertebral bodies in adults, including the tubular bones of the hands and feet in children are targeted for localisation by the disseminating tubercle bacilli (Ortner 2003: 228). The lesion distribution associated with TB in humans is illustrated in Figure 8.3. Those lesions that are most frequently observed are presented in brief below, along with those lesions and lesion locations that may point towards infection of a bovine origin.

As with any disease affecting the skeletal system, the macroscopic lesions associated with tuberculosis in both humans and animals are rarely specific and may appear in any number of pathological conditions, especially when viewed in isolation (Chapter 4). However, when an articulated skeleton is available for analysis, the information provided by lesion distribution can significantly inform the differential diagnosis process. The distribution and morphology of skeletal lesions in humans are presented in detail in several texts (see Ortner & Putschar 1985; Ortner 2003 and Aufderheide & Rodriguez-Martin 1998).

3.12.1 Vertebral column

The vertebral column (specifically the lower thoracic and lumbar vertebrae) is the most frequently affected region of the skeleton. In the absence of lesions in the vertebrae, the venturing of TB as a possible diagnosis based upon extraspinal lesions is extremely tentative (Ortner 2003: 230). The anterior vertebral bodies are most often affected resulting in cavitation and collapse leading to the characteristic angular deformity or kyphosis referred to as Pott's disease after Percival Pott an 18th century medic who studied the disease (Figure 3.23). It is rare for the posterior elements of the vertebrae to become involved (Ortner 2003: 231). The lack of involvement of the neural arch and spinous process represents another difference in the morphology of skeletal lesions between humans and animals and specifically pigs (3.8.5) and horses (section 3.9.3). A frequent complication with spinal tuberculosis is the development of a paravertebral (psoas) abscess. The abscess may track down the psoas major muscle which originates at the thoracic and lumbar region of the vertebral column and terminates at the lesser trochanter of

the proximal femur. As a result, reactive new bone formation may be present on the anterior vertebral column, the ribs or even the pelvis, particularly the internal surface of the ilia (Ortner 2003: 232). Osseous lesions affecting the pelvis may also be associated with gastro-intestinal infection, therefore, other lesions potentially indicating the presence of a psoas abscess would aid further interpretations of the location of the primary infection.

Figure 3.23 Pott's disease: cavitation and collapse leading to anterior angulation of the vertebrae (Aufderheide & Rodriguez-Martin 1998: Fig. 7.15)

3.12.2 Extraspinal lesions: the hip and the knee

Lesions affecting the hip (Figure 3.24) are the second most frequent after those of the vertebral column (Ortner 2003: 235). Lesions have also been identified in the knee; these two joints represent the primary load-bearing joints in the appendicular skeleton. The lesions associated with these joints are largely destructive and often

result in tuberculous arthritis. The acetabulum may be destroyed in severe cases and subluxation or even dislocation may also feature (Ortner 2003: 236-8).

Figure 3.24 Tuberculosis of the hip displaying granular surface within the acetabulum (Aufderheide & Rodriguez-Martin 1998: Fig. 7.16)

Tuberculosis localised within the knee joint can lead to widespread destruction of the proximal tibial articular surface (Figure 3.25) and also the distal femoral condyles. In some instances, either fibrous or bony ankylosis may occur (Ortner 2003: 240-1).

Figure 3.25 Destruction of the proximal articular surface of the tibia displaying small cavitations and exposure of the subchondral bone (Aufderheide & Rodriguez-Martin 1998: Fig. 7.17)

3.12.3 Periosteal rib lesions: Non-specific indicator of pulmonary TB?

Plaques of either woven or compact new bone located on the visceral surfaces of both human and animal ribs have been identified in a number of archaeological assemblages (Figure 3.26).

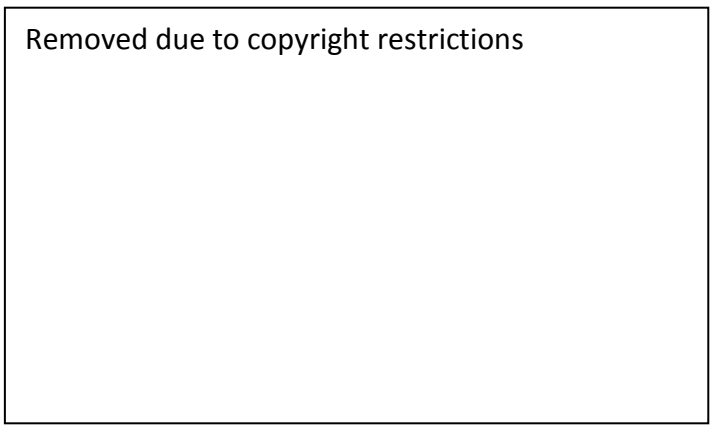

Figure 3.26 Periosteal rib lesions (Mays 2005: Figure 3)

The locations of these lesions suggest that they are related to respiratory infection; the result of pleura inflammation and a reactive bone response from the rib to which the inflamed tissue adheres (Roberts 1999: 312). In relation to animals, it is stated that tuberculosis of the pleura is a common feature of the disease but infection does not extend from the pleura to the neighbouring ribs and vertebrae (Cohrs 1967: 855). However, visceral lesions have been identified on animal ribs; specifically cattle (section 9.5.4). Therefore, although infection may not spread from the pleura directly to the bone of the ribs, the presence of infection and the resulting inflammation does invoke a periosteal response. There has been a great deal of research focused on rib lesions and their potential association with pulmonary TB (see Kelley & Micozzi 1984; Roberts 1999; Roberts *et al.* 1994; Santos & Roberts 2001; Kelley *et al.* 1994; Pfeiffer 1991; Matos & Santos 2006). These lesions have been associated with pulmonary tuberculosis in some studies on human remains, but the general consensus at present is that they '*cannot be considered as pathognomonic of pulmonary tuberculosis, and it is unlikely that this will ever be the case. However, they can be considered as indicators of non-specific chronic pulmonary disease*' (Roberts 1999: 315). This conclusion also applies to the identification of similar lesions in animal ribs. Although they cannot be considered pathognomonic of TB, they can be viewed as potential signposts for further analysis, particularly in faunal assemblages and the analysis of pathological ABGs.

3.12.4 Potential lesions associated with *M. bovis*

There are no specific lesions or lesion indicators associated with gastro-intestinal infection as a result of bTB. It is reasonable to assume that in cases of tuberculous

adenitis (scrofula), resorptive lesions observed on the cervical vertebrae could be associated with the disease. However, such lesions have not been described or attributed to bTB, as far as the author is aware. Bovine tuberculosis is most commonly associated with gastro-intestinal infection so any pathological lesions, either lytic or proliferative, within the lower abdomen could potentially be related to infection of a bovine origin. However, there have been documented cases of pulmonary bTB (section 3.11), in addition to *M. tuberculosis* affecting the intestines. Therefore, although it is impossible to determine MTB strain based upon lesion morphology and lesion location alone, those lesions observed within the pelvic region are compelling and worthy of further analysis.

3.12.5 Wetwang Slack: Gastro-intestinal infection as a result of bTB?

An individual excavated at the Iron Age cemetery site at Wetwang Slack, East Yorkshire (section 3.12.5) was identified as possessing lesions consistent with TB, possibly as a result of gastro-intestinal infection (Figures 3.27-3.28). The individual was between 18-25 years of age at death, of indeterminate sex and buried in a flexed position facing east (King forthcoming). On the anterior surface of the sacrum, there is a resorptive lesion measuring c. 3cm x 2cm exposing the trabecular bone beneath. The lesion is relatively shallow but suggests that there was a soft tissue focus within the abdominal region resulting in erosion of the cortical surface.

Figure 3.27 Resorptive lesion exposing the underlying trabecular bone. Arrow indicates modern biomolecular sample (Photo: Author)

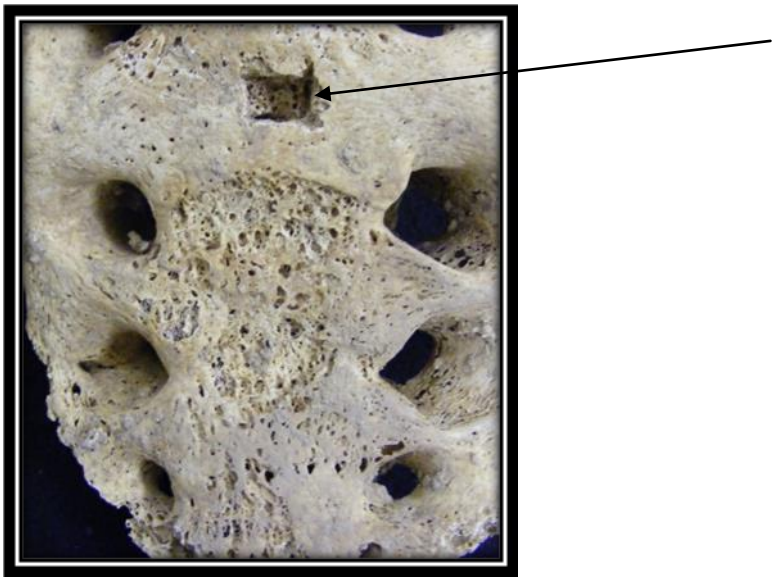

Figure 3.28 Closer view of the resorptive lesion. Arrow indicates area of sampling (Photo: Author)

3.12.6 Case Study: *M. bovis* in Iron Age Siberia

A total of 202 human skeletons dating from the 4th century BC- 4th century AD were recovered during excavation at the cemetery complex of Aymyrlyg, located in the Republic of Tyva, southern Siberia (Murphy *et al.* 2009: 2030). This semi-nomadic, mainly pastoralist community kept herds of sheep, goat, cattle and horses (Murphy *et al.* 2009: 2030). Nine individuals were observed to possess lesions suggestive of TB; four displayed non-specific rib lesions and the remaining five displayed characteristic post-cranial lesions affecting the vertebral column and joints (Figures 3.29-3.31) (Murphy *et al.* 2009: 2032).

Removed due to copyright restrictions

Figure 3.29 Destruction of the knee belonging to a male aged 25-35 years (Murphy *et al.* 2009: Fig. 4)

Removed due to copyright restrictions

Figure 3.30 Thoracic-lumbar portion of vertebral column belong to a juvenile aged 7-9 years. Extensive destruction of T12-L5 and ankylosis of L2-L4. Arrow indicates presence of kyphosis (Murphy *et al.* 2009: Fig. 6)

Four of these individuals were sampled for aDNA analysis (see Taylor *et al.* 2007). A fifth skeleton with suspected abdominal infection indicated by the presence of bone proliferation on the anterior lumbar vertebrae was also included in the sampling (Figure 3.31). This is because a similar type of proliferative lesion was observed on another skeleton that also possessed lesions more characteristic of TB. Therefore, the aDNA analysis also provided the means to investigate the aetiology of this non-specific lesion.

Figure 3.31 A combination of porosity and spiculated reactive bone on the anterior surface of an L5 vertebra, possibly indicating abdominal infection (Murphy *et al.* 2009: Fig. 5)

In four of the five skeletons sampled, *M. bovis* DNA was successfully recovered and amplified, identifying the presence of bTB in this Iron Age semi-nomadic community of Siberia. These results represent the first identifications of *M. bovis* in archaeological human remains, the colder climate undoubtedly providing an environment more conducive to DNA preservation (Murphy *et al.* 2009: 2037). In light of this, it is reasonable to assume that *M. bovis* was far more prevalent in past

human communities, particularly rural communities, than it is given credit for. The reactive bone observed on the anterior lumbar vertebrae of two individuals was amongst the positive results. As a result, the authors cautiously suggest that this lesion type may be used as a possible indicator of *M. bovis* infection (Murphy *et al.* 2009: 2037). In the context of these results and the accompanying lesions, the aetiology of this non-specific lesion can be more confidently linked to an abdominal infection caused by *M. bovis.* However, in other skeletons, this type of lesion may well be associated with an overlaying psoas abscess, originating from a pulmonary as opposed to abdominal infection. Similar lesions attributed to a possible psoas abscess are illustrated by Ortner (2003, Fig. 10-4).

Mycobacterium bovis infection in humans is generally interpreted as a spillover infection and as such is not regarded as self-maintaining (Taylor *et al.* 2007: 1243; O'Reilly & Daborn 1995: 15). However, in certain circumstances such as those demonstrated by this case study, if bTB is present within a community that are in close and regular contact with their animals and the infection is in some cases pulmonary, then there is the possibility that the infection in humans could evolve from a spillover infection to a reservoir of infection, putting any uninfected animals at risk. Unfortunately, there was no reference to any palaeopathology in the faunal assemblage from this site. With *M. bovis* confirmed in the human population, it is likely to have been present in the animals too.

3.13 Pathogenesis and skeletal lesion summary

With reference to the medical and veterinary literature, tuberculosis of the skeletal system in both humans and animals would appear to follow a similar pathogenesis, resulting in a broadly similar lesion distribution. The main difference highlighted between human and animals is the periosteal reaction of the latter to infection. Animals are more prone to periostosis, formed either as a reaction to infection or as an attempt at repair. Although the lesions, particularly those affecting the vertebrae in humans, are characteristic in appearance, the reality remains that they could belong to any number of diseases, especially when viewed in isolation as is most often the case in zooarchaeology. The differential diagnosis of MTB complex infection has been addressed in detail in Chapter 4. Although, *M. bovis* is known to cause both pulmonary and gastro-intestinal infection in humans, identifying a specific lesion that represents a skeletal indicator for bovine infection is improbable. However, lesions affecting the lumbar vertebrae as highlighted by Murphy *et al.* (2009) (Figure 3.31) and also the pelvis and sacrum (Figures 3.27-3.28) may provide the means to further explore aetiology through biomolecular methods.

3.14 Tuberculosis: A literature review

There have been a number of comprehensive reviews concerning the history of TB in general, including most notably: Meinecke (1927), Castiglioni (1933), Pease (1940), Chalke (1962), Warring (1981) and Grmek (1989). The following section focuses on presenting a brief review of bTB and the historical, archaeological and scientific evidence for its presence in the human and animal populations of the past.

This is based upon information recently published by the author (see Wooding 2010).

3.14.1 Bovine tuberculosis in humans

Calculating the true prevalence of bTB in humans in the present day is difficult to determine without the aid of scientific analyses. Therefore, attempting to calculate its crude prevalence in the more distant past is an impossible feat, especially in light of the osteological paradox (section 2.5.4) (see Wood *et al.* 1992). However, through the combined use of historical evidence and the application of both ancient DNA (aDNA) and mycolic acid analyses on archaeological material, support for its presence can be established, thus providing a platform from which to develop a better understanding of its impact in past communities.

'Tuberculosis' was only relatively recently coined in 1839 by Professor J.L. Schönlein (Dormandy 1999: 9). Prior to this, the disease was referred to by a number of different names, including most prominently: consumption, scrofula, the white plague, the king's evil, tabes and phthisis. Although this makes continuity difficult to achieve when studying the disease, each name when studied in more detail provides a deeper understanding of how this disease was perceived in the past. Reference to TB or a disease similar to TB, is made in several sources, including those by Hippocrates, Aristotle, Aretaeus of Cappadocia and Galen, in addition to writings within the Susruta and Aynrveda (ancient Hindu texts) (Castiglioni 1933: 8) (section 2.2). As Meinecke stated (1927: 381), *'Hippocrates describes consumption so often and so fully that we are forced to the conclusion that it must have been very*

prevalent already in his day'. Although useful, literary and historical records are ultimately subjective accounts and undoubtedly contain inaccuracies. Their consultation is fraught with problems, and it is essential that caution be exercised in their interpretation, especially where the descriptions of different diseases are the subject. However, a number of sources have revealed a detailed insight into the presence of TB in the past, which is supported to a degree by the fact that both archaeological and biomolecular evidence demonstrate that TB is a disease of considerable antiquity. Archaeological evidence supporting the presence of TB is well documented the world over (section 1.3). One of the earliest examples of TB identified dates to the Neolithic; it was excavated in Liguria, Italy (see Formicola *et al.* 1997; Canci *et al.* 1996). More recently, *M. tuberculosis* was identified in a Neolithic female and an infant in Israel (see Hershkovitz *et al.* 2008).

Frequent reference is made to pulmonary TB in the *Hippocratic Corpus,* but there is also mention of the non-pulmonary form, scrofula (Meinecke 1927: 383). The name scrofula derives from the Latin term '*scrofa*', meaning pig or sow (Kiple 1997: 44). This manifestation of TB results in the characteristic swelling of the neck lymph glands (Cartwright & Biddiss 2004: 154), and in particular, the cervical lymph nodes (Dormandy 1999: 4). In some medical circles as late as 1891, scrofula was still regarded as a separate disease from the more commonly encountered pulmonary TB (Chalke 1962: 304). However, it soon became clear that scrofula represented the non-pulmonary manifestation of TB (tuberculous adenitis) (Chalke 1962: 304), most likely of bovine origin having been transmitted through the ingestion of contaminated meat and milk (Kiple 1997: 44).

In the Middle Ages, some believed the touch of a king could cure scrofula, hence it became referred to as 'The King's Evil' (Kiple 1997: 44). Those afflicted waited in vast numbers to be touched by the monarch, with Charles II, King of England, reported to have touched at least 92,107 people up until his death in 1683 (Cartwright & Biddiss 2004: 154). Queen Anne was the last English monarch to perform 'the touch' in the early 18th century (Cartwright & Biddiss 2004: 154). Although these statistics cannot be relied upon as definitive, they do provide some indication of the general prevalence of the non-pulmonary form of this disease in the Middle Ages and Early Modern Period (Renaissance) (Dormandy 1999: 4). Unfortunately, in prehistoric times we have no way of knowing the prevalence of scrofula in the human population. The potential was certainly there; unpasteurised milk was being consumed in the Iron Age and earlier (section 5.4.4). However, there have been no specific osseous lesions identified affecting the cervical vertebrae that may be linked with this aetiology.

Not all cases of TB identified in human skeletal remains from rural farming communities, will necessarily be bovine in origin. For example, during the excavations of a medieval churchyard at the rural site of Wharram Percy, nine cases of skeletal TB were identified. Instead of the expected identification of *M. bovis* as the causative strain, *M. tuberculosis* was identified in all nine cases (Mays 2005: 131). Similar analyses on three cattle ribs from the same site displaying rib lesions were negative. Either the animals were free of TB at this site or the complex taphonomic history of the faunal remains rendered the bacterial DNA too degraded for recovery (Mays 2005: 131).

3.14.2 Bovine tuberculosis in animals

The disarticulated and fragmented nature of zooarchaeological assemblages precludes the identification of diseases that require the analysis and recording of lesion distribution. As a consequence, research focused upon the identification of systemic diseases in past animal populations is regrettably lacking. There is a wealth of historical evidence to support the notion that animals suffered from systemic diseases in the past, however, identifying this in the archaeological record is challenging, but not beyond the realms of possibility.

Bovine tuberculosis is referred to by Columella in *c*. AD 50, clearly illustrating that bovine consumption or, at the very least, pulmonary disorders that resembled consumption was a recognised malady of animals (Meinecke 1927: 395; Pease 1940: 386). Columella writes: '*…Ulceration of the lungs is also a source of great destruction to cattle…Thence arise cough and emaciation and finally consumption attacks them.*' (*De Re Rustica*, VI, 14, I, cited in Meinecke 1927: 395-6).

More detailed descriptions appearing to refer to bTB are contained within the '*Mulomedicina Chironis*' written by Claudius Hermerus in *c.* AD 400 (Meinecke 1927: 398). This text represents one of the oldest veterinary literary resources and clearly conveys a full awareness of a disease believed to be bTB in animals (Meinecke 1927: 398). The symptoms were outlined as follows: '*At first no fever, but a wasting condition growing steadily worse, till the bones protrude everywhere; the animal chews and eats abnormally because it is constantly hungry; a hard excrement is evacuated and the diseased animal lives for a long time; eventually it can no longer*

regain its feet and consequently eats lying down, as if resting. The disease consumes the marrow which is not benefited by food taken in; the liver becomes smaller and finally wastes away; by degrees the whole body is consumed like a tree which has been deprived of its larger roots, though sustained temporarily by the smaller ones, but in the end it gradually withers up.' (*Mulomedicina* (Oder), 47, 48, cited in Meinecke 1927: 398). This excerpt presents a detailed account of a chronic wasting disease afflicting cattle. Although the symptoms listed appear to fit those outlined for bTB in cattle (section 3.7), the reality is that many diseases could be made to fit this description, including other infectious diseases and neoplasia.

Later in AD 420, Vegetius demonstrates that TB was seen as a disease that could affect both humans and animals, by stating: '*Animals suffer with consumption just like men'* (Meinecke 1927: 399). Although the use of 'consumption' cannot be taken as definitive evidence for the presence of bTB, it clearly illustrates the beginnings of awareness in relation to zoonotic disease (Meinecke 1927: 399). Further evidence for the acknowledgement of TB as a zoonotic disease is also demonstrated in the writings of the *Mosaic Laws* within the *Talmud*. According to the entries within the *Talmud* dating to the 2nd and 5th centuries AD (Steele & Ranney 1958: 908), upon slaughter, if an animal displays soft tissue lesions located between the pleura and lungs, it is deemed unfit for consumption (Wight 1942: 237). Wight states: '*Since pleural adhesions often accompany tuberculosis of the lungs, the possibility of transmission of the disease from animal to man may have been recognised at that time'* (Wight 1942: 237). It is important to highlight that pleural lesions are non-specific and could be indicative of any number of chronic respiratory infections,

including for example, pneumonia and bronchitis (see Boden 2005). As a result, visceral rib lesions identified in animal remains must never be viewed as definitive evidence for bTB, especially in fragmentary and co-mingled faunal remains. In articulated remains (ABGs), they can be seen as supporting evidence for a possible diagnosis of pulmonary bTB amongst others, but only when there are other contributory lesions to support such a diagnosis.

As far as the author is aware, there have been no published macroscopic or biomolecular identifications of bTB in the faunal archaeological record. There are, however, two cases of MTB complex confirmed through aDNA analysis. The first is a case of *M. tuberculosis* identified in an Iroquoian dog dating to the 16th Century (section 3.9.2) (Bathurst & Barta 2004), and the second is confirmed MTB complex DNA in a number of bison bones (Rothschild *et al.* 2001). The bison bones, amongst others, were excavated from Natural Trap Cave, Wyoming, and were reported as displaying a rare but 'characteristic' lesion associated with TB, namely '*granulomatous infection, involving undermining of subchondral surfaces'* (Rothschild *et al.* 2001: 2). *Mycobacterium tuberculosis* (MTB) complex DNA was amplified, but further spoligotyping was unsuccessful. Although the causative strain could not be determined, it most closely resembled modern *M. africanum and M. tuberculosis*. The authors postulated that the age of the bones (17,000 BP) was the underlying reason for the inability to pinpoint the specific strain responsible. In addition, at this point in the evolution of the MTB complex, speciation of differing strains may not yet have occurred (Rothschild *et al.* 2001: 5). This explanation would appear to fit with the phylogenic research presented by Brosch *et al.* (2002).

Bendrey *et al.* (2008) report the presence of pathological lesions within two Iron Age horse skeletons from southern Britain. Upon differential diagnosis, these lesions were thought to be bacterial in origin, with TB and brucellosis amongst the differential diagnoses. Unfortunately, the aDNA analysis was inconclusive, and no definitive diagnosis could be entertained. However, this does not mean that these horses did not suffer from TB, but it does suggest that its identification both macroscopically and microscopically in fragmented animal remains may prove extremely difficult.

3.15 Conclusion

Bovine tuberculosis is a zoonotic disease of considerable antiquity. It has been confirmed for the first time in Iron Age human remain in Siberia (section 3.12.6), categorically demonstrating its ability to infect humans in the past. Although bTB has yet to be formally identified in archaeological animal remains, there is no doubt that it was present, supported by the preliminary results of this research.

4. BOVINE TUBERCULOSIS: DIFFERENTIAL DIAGNOSIS

'The list of diseases capable of mimicking tuberculosis is staggering…..'

(Zimmerman & Kelley 1982: 106)

4.1 Introduction

There are several diseases that warrant consideration in the differential diagnosis of bTB for both humans and animals, a number of which are also zoonoses. In relation to TB in human palaeopathology, Zimmerman & Kelley (1982: 106) stated: *'The list of diseases capable of mimicking tuberculosis is staggering…..Fortunately, most of these can be eliminated based on their overall lesion pattern or their infrequent skeletal involvement.'* This situation is comparable for zooarchaeology, and a list of the main diseases/pathological conditions to consider for both humans and animals are provided in Table 4.1. This list does not outline those diseases that only affect humans, these include: histiocytosis – X, sarcoidosis, Scheuermann's disease and vertebral compression fracture. The list compiled is aimed specifically at the lesion distributions observable in articulated and semi-articulated skeletons. With reference to the information provided below, the potential list of aetiologies could be narrowed to a handful. The list of differential diagnoses for a non-specific, isolated lesion, however, would remain extensive, but through the consideration of lesion morphology and lesion location, a better discrimination could be achieved. At the end of each differential diagnosis section, a summary reference table is provided.

Table 4.1 Differential Diagnoses for bTB in human and animal bone

Aetiology	Primary Differential Diagnoses for bTB in Animals and Humans
Bacterial disease:	brucellosis, actinomycosis, pyogenic osteomyelitis
Hydatid disease (parasitic):	echinococcosis
Mycotic infection:	coccidioidomycosis, blastomycosis (animals)
Neoplasm:	primary malignant bone tumours (osteosarcoma), secondary metastatic bone tumours
Joint pathology:	septic arthritis, rheumatoid arthritis, ankylosing spondylitis

4.2 Bacterial Disease

There are numerous species of bacteria related to both specific and non-specific infections that possess the potential to cause illness and skeletal change in animals and humans. Of these, there are two specific and one non-specific infection that require detailed consideration in the differential diagnosis of TB and bTB: brucellosis (section 4.2.1), actinomycosis (section 4.2.2) and pyogenic osteomyelitis (section 4.2.3). These are outlined below, including the ways in which the lesions differ from those associated with skeletal TB in dry bone. Other diseases that would also potentially display morphologically similar lesions include actinobacillosis in animals and typhoid fever in humans; however, these will not be discussed here because of their lack of specific bone involvement.

4.2.1 Brucellosis

Brucellosis is an infectious zoonotic disease caused by bacteria belonging to the *Brucella* genus. There are five main species that can cause illness in both humans and animals: *B. abortus*, *B. melitensis*, *B. suis*, *B. ovis* and *B. canis* (Boden 2005: 95). In addition to humans, a wide array of domesticated and wild animals can be affected, including most notably: cattle, horse, sheep, goat, pig, dog, poultry, deer, hares, harbour porpoise, foxes and rodents (Boden 2005: 95). The main reservoirs for zoonotic transmission to humans are cattle, sheep, goat, pigs and horses (Aufderheide & Rodriguez-Martin 1998: 192). In humans, this disease is referred to colloquially as undulant fever or Malta fever (Thomson 1979: 150) and, in cattle as Bang's disease or contagious bovine abortion, the latter referring to the tendency for pregnant cows to abort between the 5th and 8th month of gestation (Boden 2005: 96; Blood & Henderson 1968: 370). D'Anastasio *et al.* (2009) recently reported suspected evidence for brucellosis in the lumbar vertebrae of the early hominin species *Australopithecus africanus*. In addition to this, the disease is also suspected (alongside a possible aetiology of bTB) in two Iron Age horse skeletons (see Bendrey 2004; Bendrey *et al.* 2008), clearly highlighting the potential antiquity of this zoonosis that is similar to that of bTB.

The disease is spread haematogenously to sources of bone marrow (Cohrs 1967: 860), where granulomatous lesions may then localise resulting in the formation of intra-osseous abscesses (Siegel 1975: 29). These osseous lesions are usually associated with a combination of both bone loss and bone formation (Cohrs 1967:

860; Siegel 1975: 29; Baker & Brothwell 1980: 76). *Brucella abortus* targets (amongst others) the joint capsules and bursae (Blood & Henderson 1968:369), providing the means for extension to nearby skeletal structures. When the skeleton does become involved, the primary predilection sites in animals (specifically, cattle, horse and pigs) are the vertebrae and joints, resulting in vertebral spondylitis (Siegel 1975: 29) and arthritis. In cattle, arthritis of the knee joint has been reported (Lignereux & Peters 1999: 345). In pigs, *B. suis,* is reputed to cause lameness and posterior paralysis as a result of both arthritis and osteomyelitis of the lumbar and sacral vertebral bodies (Blood & Henderson 1968: 380; Palmer 1993: 104). In the horse, the cervical and lumbar vertebrae are the primary skeletal elements affected. That said, vertebral body osteomyelitis in horses has been attributed in the past to both *B. abortus* and *M. bovis* (see Collins *et al.* 1971; Kelly *et al.* 1972; Markel *et al.* 1986), emphasising the importance of brucellosis as a differential diagnosis for bTB in this species. Also in horse, *B. abortus* favours localisation in the muscles, tendons, bursae and joints (Denny 1973: 121). Two primary examples of this include poll evil and fistula withers, inflammatory conditions of the supra-atlantal (poll evil) and supra-spinous (fistula withers) bursae (O'Sullivan 1981: 103). The aetiology of these conditions is often associated with *B. abortus* (see Duff 1936; O'Sullivan 1981), in addition to *Actinomyces bovis* (O'Sullivan 1981: 103) and *Streptococcus zooepidemicus* (Bendrey *et al.* 2009). The supra-atlantal bursa is positioned dorsally in relation to the atlas vertebra, with the supra-spinous bursa dorsal to the first thoracic vertebral spinous process, creating a cushion between the underlying skeletal elements and the nuchal ligament above (Baker & Brothwell

1980: 127). Infection of these specific bursae can lead to rupture and extension to the underlying bones (Baker & Brothwell 1980: 64). In addition to this, infection involving the nuchal ligament can also lead to pathological change affecting the regions of attachment (the occipital region of the skull and the spinous processes of the thoracic vertebrae) (Smith & Jones 1961: 398). A potential case of poll evil affecting the occipital region of a horse skull was recently highlighted by Bendrey *et al.* 2009. The horse displayed a larger than normal enthesophyte at the point of ligament attachment (*ligamentum nuchae*) in addition to both bone formation and bone loss (Figure 4.1) (Bendrey *et al.* 2009).

Figure 4.1 Occipital region of horse skull displaying enthesophyte and areas of new bone formation (A, B & C) (Bendrey 2009: fig 4)

The disease in humans favours the vertebral column and the sacroiliac joint in adults, and the knee and hip joints in children (Ortner 2003: 216). In the vertebrae, the lesions are often multiple and initially destructive with abscess formation leading to lytic lesions, but with no sequestrum (Aufderheide & Rodriguez-Martin 1998: 192). Progression of the disease may result in the perforation and/or destruction of the intravertebral disk allowing the disease to spread into adjacent vertebrae. In the later stages of the infection, there is an emphasis on healing and sclerotic repair (Aufderheide & Rodriguez-Martin 1998: 192), the latter only visible on a radiograph. In some cases, this may lead to ankylosis of affected vertebrae (Ortner & Putschar 1981: 138). The difference between these lesions and those associated with TB is the lack of vertebral collapse and subsequent kyphosis in the former (Ortner & Putschar 1981: 138). In addition to this, in both humans and animals, there is more emphasis on new bone formation and repair, while TB is predominantly destructive (Aufderheide & Rodriguez-Martin 1998: 193). A difference identified in the veterinary literature between the morphology of tuberculous osseous lesions in humans and animals is the greater emphasis on new bone formation in the latter (section 3.8.5). Therefore, this may not be the best criteria to focus upon when differentiating brucellosis from bTB in animal bone. Table 4.2 summarises the main skeletal predilection sites for this pathological condition.

Table 4.2 Differential Diagnosis: Brucellosis

Bacterial Disease (I): Brucellosis		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: vertebrae, sacroiliac joint in adults, knee and hip in children **Animals:** vertebrae (horse: cervical, lumbar; pig: lumbar, sacral), joints (cattle: knee), skull (horses: occipital region – see 'poll evil')	**Lesion morphology:** predominantly lytic with later sclerosis and possible ankylosis **Humans:** multiple lytic lesions, abscess formation, sclerosis, cavitation without sequestra or collapse, 'parrot beak' osteophytes on anterior vertebrae, possible ankylosis of vertebrae, arthritis affecting joints **Animals:** spondylitis/arthritis/osteomyelitis (the latter esp. in horses) (vertebrae), arthritis with little destruction (joints) **Investigate:** signs of poll evil and fistulas withers (horse)	**Humans:** no collapse/kyphosis, no sequestra, no paravertebral abscess, little destruction of joints, more emphasis on sclerotic repair **Animals:** More emphasis on bone proliferation than observed in humans (similar to bTB)

4.2.2 Actinomycosis

Actinomycosis is a specific bacterial infection caused by *Actinomyces bovis* (Baker & Brothwell 1980: 76; Palmer 1993: 106). This disease is predominantly a malady of cattle, but can also affect pigs, horses, dogs, deer and humans (Cohrs 1967: 858). *A. bovis* is not especially virulent and has been described as *'...an obligatory parasite on the mucous membranes of the oropharynx of a number of animal species...'* (Palmer 1993: 106). Infection is usually opportunistic, the bacterium gaining access to the soft tissue and bone through either injury or assault (Siegel 1975: 29). When the skeleton does become involved, lesions principally take the form of a rarefying osteomyelitis (Blood and Henderson 1968: 406), although periostitis has also been documented (Palmer 1993: 107). The primary skeletal predilection site in animals is the mandible and less commonly the maxilla; the impaction of cereal grains and plant matter between the teeth of ruminants provides the means for bacterial access, with other possibilities including trauma and complications associated with periodontal disease (Palmer 1993:107). The characteristic mandibular swelling associated with the disease in cattle is referred to as 'lumpy jaw' (Figure 4.2).

Figure 4.2 Cow with actinomycosis 'lumpy jaw' (Smith & Jones 1961: fig 140a)

The infected mandible upon maceration is often swollen in appearance with multiple irregular lytic focuses (Figure 4.3) (Baker & Brothwell 1980: 76; Lignereux & Peters 1999: 346). In this form, the disease is very similar to, and can often be mistaken for, actinobacillosis (Boden 2005: 8). This disease possesses a similar pathogenesis to actinomycosis and is referred to as 'wooden tongue' (Blood & Henderson 1968: 408).

Figure 4.3 Bovid mandible with lytic lesions indicative of actinomycosis (Baker & Brothwell 1980: fig 15b)

The post-cranial skeleton is rarely involved in actinomycosis (Cohrs 1967: 858; Baker & Brothwell 1980: 76). However, the exception to this rule is the sternum, which can become pathologically affected through direct extension of reticulitis (Ostertag 1922: 604, as cited by Lignereux & Peters 1999: 346). In animals, tuberculous lesions of the mandible and maxilla are not as characteristic of the disease process as they are in actinomycosis or actinobacillosis. However, tuberculous lesions can affect any bone in the skeleton (in both humans and animals (section 8.3) so it cannot be ruled out as a possible aetiology if a destructive lesion of the mandible is identified in a faunal assemblage. Destructive lesions associated with the ventral surface of the sternum should include actinomycosis along with TB as potential differential diagnoses.

In humans, the disease is primarily caused by *A. israelii*, a bacterium found within the oral cavity. Lesions are not exclusive to the mandible and maxilla; in fact, any bone can be affected (Aufderheide & Rodriguez-Martin 1998: 193). Post-cranially, the thoracic and abdominal regions are the principal focuses for involvement, with the main predilection sites including the vertebrae, ribs, sternum and pelvic girdle (Ortner 2003: 319). Skeletal involvement is more often than not the result of direct extension from a soft tissue focus and is rarely haematogenous (Ortner 2003: 320). Involvement of the periosteum leads to hypervascularity and sub-periosteal new bone formation, although bone destruction is also characteristic, with no sclerotic repair (Ortner 2003: 320). In the vertebrae, the transverse processes may become involved along with the ribs; however, lytic lesions affecting the vertebral bodies do not penetrate too deeply and the intravertebral disk is usually spared as are the neural arch and spinous processes (Ortner & Putschar 1981: 220). The main difference between actinomycosis and vertebral tuberculosis is the lack of vertebral collapse and kyphosis and the preservation of the intravertebral disk in the former (Aufderheide & Rodriguez-Martin 1998: 195). Table 4.3 summarises the main skeletal predilection sites for this pathological condition.

Table 4.3 Differential Diagnosis: Actinomycosis

Bacterial Disease (II): Actinomycosis		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: any bone can be affected: mandible, maxilla, vertebrae (cervical, thoracic, lumbar), ribs & sternum **Animals: affects large range of animals: cattle, horses, sheep, goat; mandible is primary predilection site, sometimes maxilla affected. Post-cranial skeleton rarely involved, although sternum sometimes involved in cattle**	**Lesion morphology: mixed** **Humans: lytic lesions sometimes with periosteal bone formation but also with no sclerotic repair, lytic lesions affecting vertebrae are shallow** **Animals: osteomyelitis, multiple irregular lytic lesions, sometimes associated with periosteal bone formation**	**Humans: no collapse/kyphosis, intravertebral disk preserved, shallow lytic lesions, involvement of transverse processes** **Animals: bTB can affect the mandible, so lytic lesions would have to be carefully examined. They would most likely be more regular in appearance and less expansive. Any lytic or reactive bone lesions on the ventral surface of sternal fragments would require detailed consideration**

4.2.3 Pyogenic Osteomyelitis

Pyogenic osteomyelitis refers to a suppurative infection of the bone marrow that originates within the medullary cavity (Boden 2005: 504, 577). A large array of pus-forming bacteria associated with both specific and non-specific infections possess the potential to cause osteomyelitis, in addition to some parasites, viruses and fungi (Ortner 2003:181). Pyogenic bacteria can gain access to the medullary cavity in one of three ways: as a result of trauma (i.e. compound fracture) or penetrating wound, by direct extension from a soft tissue focus or via the blood-stream or lymphatic system (Ortner 2003: 181; Boden 2005: 77). In the overwhelming majority of cases, the causative bacterium in humans is *Staphylococcus aureus* (Aufderheide & Rodriguez-Martin 1998: 172). In addition to *Staphylococcus* spp., haematogenous osteomyelitis in cattle is often caused by *Actinomyces pyogenes*, *Escherichia coli*, *Klebsiella* spp., *Salmonella* spp. and *Streptococcus* spp. (Palmer 1993: 104).

In animals, the post-cranial bones most commonly affected are the tibia, radius and ulna. To a lesser extent, the metapodia in ruminants are targeted followed by the thoracic and lumbar vertebrae in pigs (Baker & Brothwell 1980:64). Vertebral body osteomyelitis has also been reported in horses (see Markel *et al.* 1986). In two horses, *Streptococcus* spp. was identified as the causative agent, with a third identified as *Aspergillus* spp., clearly indicating that fungi can also cause osteomyelitis (Markel *et al.* 1986: 633). In humans, the knee joint is favoured, followed by the distal tibia and proximal femur (Aufderheide & Rodriguez-Martin 1998: 174). However, haematogenous osteomyelitis may affect any bone of the

skeleton, as Douglas and Williamson highlighted in relation to the infection in animals: *'...osteomyelitis may occur anywhere in a bone and anywhere in the skeletal system and there are no predilection sites.'* (Douglas & Williamson 1970: 41). This statement is generally speaking accurate; however, both in young animals and juvenile humans, the long bones and specifically the metaphyses do form primary predilection sites (Baker & Brothwell 1980: 64; Ortner 2003: 181). This is due to a combination of anatomy and biology in the developmental stages of long-bone growth. The metaphysis is highly vascular but the blood vessels are small and are shaped in such a way as to minimise the speed of blood flow, making it more sluggish (referred to as passive hyperaemia); thus infective organisms can become easily ensconced, leading to multiplication, destruction of the blood vessels and eventual access to the bone marrow (Baker & Brothwell 1980: 64-66; Markel *et al.* 1986: 634). If this happens, a purulent focus develops, and unopposed, the exudate extends along the medullary cavity (Baker & Brothwell 1980: 66). In adults, infection may penetrate the articular cartilage and extend into the joint space, possibly leading to secondary arthritis (Baker & Brothwell 1980: 66). However, in the young, the presence of the growth plate prevents spread into the epiphysis and joint, but the developing cortex in this proximal portion of the bone is vulnerable and the exudate can extend beneath the periosteum (Ortner 2003: 182). The combined pressure of the exudate both internally and externally leads to the loss of the blood supply and the affected areas of the bone become necrotic (Baker & Brothwell 1980:67). Osteomyelitis of long bones, especially chronic infection, is often characterised by the presence of a sequestrum, involucrum and a cloaca for the

drainage of purulent material (Figure 4.4) (Aufderheide & Rodriguez-Martin 1998: 172). In some cases, an initial infection in the metaphysis may become contained within a fibrous capsule of granulation tissue forming a Brodie's abscess (Aufderheide & Rodriguez-Martin 1998: 178; Palmer 1993: 103). These abscesses are oval or circular in shape and are only visible using radiography or destructive analysis (cross-sectioning). The margins of the lesion display sclerotic change; on a radiograph this would manifest as increased radiopacity, indicative of increased bone density (Douglas & Williamson 1970: 33).

The main difference between osteomyelitis caused by TB and non-specific pyogenic osteomyelitis lies in the presence or absence and size of the sequestrum. In tuberculous osteomyelitis, sequestra are either much smaller in size or completely absent (Aufderheide & Rodriguez-Martin 1998: 140). In humans with vertebral osteomyelitis, kyphosis and the formation of paravertebral abscesses are rare (Aufderheide & Rodriguez-Martin 1998: 140).

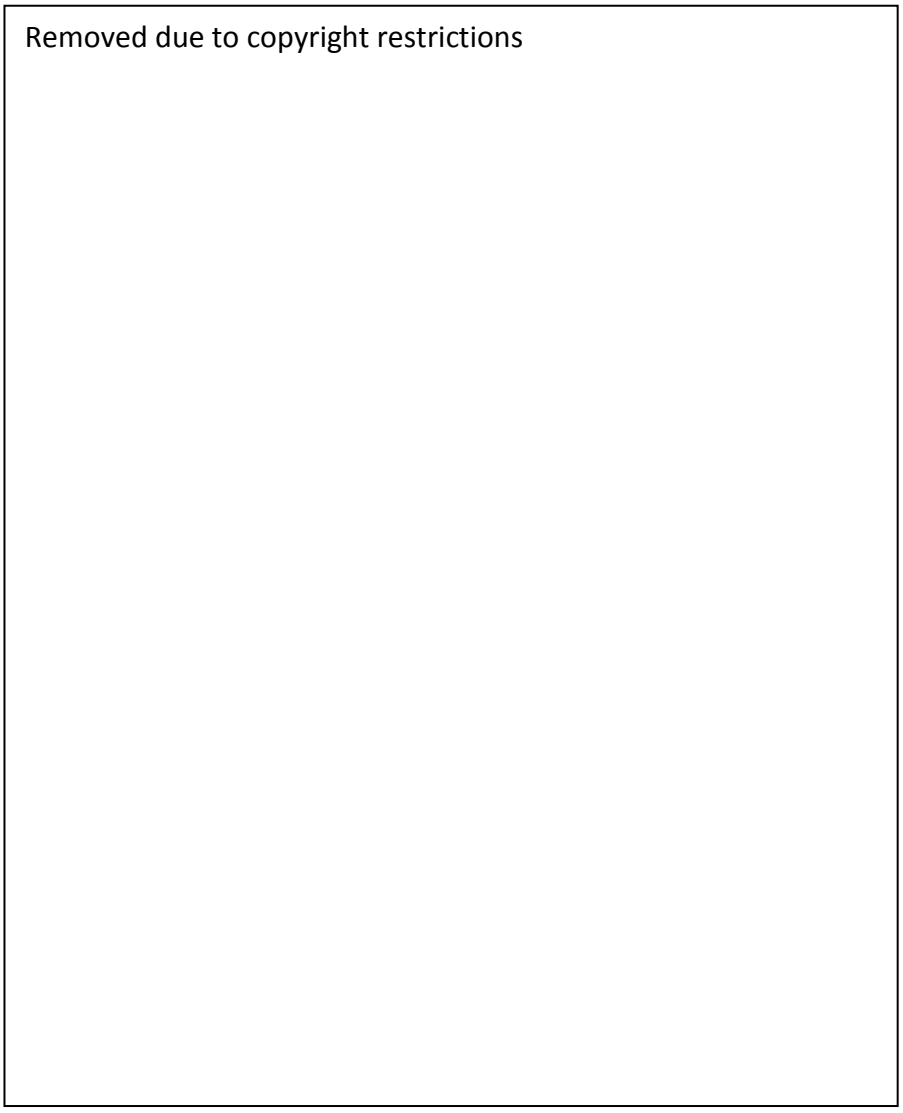

Figure 4.4 Osteomyelitis in a human tibia displaying an involucrum and multiple cloacae (Ortner 2003: fig 9-4)

However, abscesses have been identified in horses with non-specific pyogenic vertebral osteomyelitis (see Markel *et al.* 1986). Where osteomyelitis is identified on fragmented faunal bones, it becomes exceptionally difficult/near impossible to identify whether the causative agent was a specific or non-specific infection. The

only scenario in which the aetiology may be surmised would be if the bone had been subject to trauma, for example, a compound fracture or if the infection was associated with the mandible, of which actinomycosis and actinobacillosis would be prime candidates. This is why a good understanding of the lesion distribution and morphology is so important in determining aetiology, especially for systemic diseases like TB/bTB. Table 4.4 summarises the main skeletal predilection sites for this pathological condition.

Table 4.4 Differential Diagnosis: Pyogenic Osteomyelitis

Bacterial Disease (III): Pyogenic Osteomyelitis		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: any bone can be affected but mainly metaphyseal region of long bones: knee joint, distal tibia, proximal femur **Animals: any bone can be affected but mainly post-cranial skeleton: tibia, radius, and ulna. To a lesser extent the metapodia in ruminants and thoracic and lumbar vertebrae in pigs and horses.**	**Lesion morphology: mixed** **Humans: osteomyelitis: presence of sequestra, involucrum and/or cloacae, sclerotic circular/oval lesion (Brodie's abscess) (viewed using radiography) sometimes seen. In adults articular cartilage may be penetrated leading to secondary arthritis, growth plate prevents this in sub-adults** **Animals: osteomyelitis: presence of sequestra, involucrum and/or cloacae, sclerotic circular/oval lesion (Brodie's abscess) (viewed using radiography) sometimes seen.**	**Humans: presence and size of sequestrum, vertebral kyphosis is rare, paravertebral abscesses are rare, more emphasis on bone proliferation** **Animals: very difficult to distinguish between specific and non-specific pyogenic osteomyelitis. Be aware that horses can develop paravertebral abscesses in cases of pyogenic osteomyelitis**

4.3 Hydatid Disease

Hydatid disease refers to infection with a particular species of tapeworm. The main disease that may cause skeletal change in humans and animals is echinococcosis (section 4.3.1). There are numerous other parasitic infections that result in illness, including liver fluke, caused by flat worms (Boden 2005:420). However, these rarely involve the skeletal system.

4.3.1 Echinococcosis

Echinococcosis is a common parasitic infection referred to in some texts as hydatid disease. The instigator of this infection is the tapeworm (in its larval stage of development) belonging to the *Echinococcus* genus. The primary species that causes illness in both humans and animals is *Echinococcus granulosus* (Ortner 2003: 337). The dog and the fox form the primary hosts for this parasite and aid in its dissemination to intermediate hosts by depositing/shedding eggs in their faeces; these are then consumed by grazing animals, particularly cattle, horses and sheep (Boden 2005: 349). Humans can become infected in several ways, including by direct contact with either the primary or intermediate hosts or contact with contaminated food or water (Ortner 2003: 337). After consumption, the eggs hatch and gain entry to the portal vein, where they are transported to the liver (Boden 2005: 349). Some develop into hydatid cysts within the liver, although other organs or tissues, including, those of the lungs, kidney, spleen, brain or bone marrow may become infected (Ortner 2003: 337; Boden 2005: 349). In soft tissue, a fibrous

capsule is formed around the fertile cyst, which contains the scolices (numerous tapeworm heads). If a cyst of this nature ruptures, each head could form a new cyst in the surrounding tissue.

In humans the frequency of skeletal involvement is reportedly just 2% (Ortner 2003: 338), and similarly in animals, the disease is primarily one of the soft tissue with skeletal lesions a rarity (Baker & Brothwell 1980: 171; Ligneruex & Peters 1999: 346). However, when the skeleton is affected, it is the cancellous bone rich in hematopoietic marrow that forms the main predilection site. The primary targets in humans are the vertebral bodies and metaphyseal portions of the long bones and often just a single bone or adjacent bones are involved (Ortner 2003: 338). In bone, there is no large cyst formation, but a series of multiple small cysts that spread between the trabecular bone, resulting in bone lysis. In some cases, the growth of these cysts and subsequent loss of bone, particularly in the vertebrae can lead to a loss of integrity and vertebral collapse, which may bear a resemblance to the classic kyphosis associated with spinal tuberculosis (Ortner 2003: 338). However, the posterior parts of the vertebra, in addition to the transverse processes, are often involved in echinococcus, unlike the situation associated with TB (Ortner 2003: 338). If infection is in the medullary cavity, it does not spread to involve the joint. The affected parts of the long bone may become necrotic with the formation of sequestra and eventual pathological fracture – similar to osteomyelitis but without the new bone formation or sclerotic repair. In both humans and animals once the hydatid cysts have died, they calcify and become encapsulated in bony plates,

which may survive and be retrievable (if recognised) upon the excavation of both human and animal burials (Figure 4.5) (Aufderheide & Rodriguez-Martin 1998: 242; Baker & Brothwell 1980: 171).

Figure 4.5 Possible mineralised hydatid cysts (Ortner 2003: fig 12-13a)

However, in some cases of gastro-intestinal TB, the mesenteric lymph nodes may become infected and calcify, resembling a hydatid cyst (Aufderheide and Rodriguez-Martin 1998:244). Table 4.5 summarises the main skeletal predilection sites for this pathological condition.

Table 4.5 Differential Diagnosis: Echinococcosis

Hydatid Disease: Echinococcosis		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: long bone metaphyses and vertebral bodies but skeletal lesions are rare. **Animals: primary hosts: dog and fox, can also affect grazing animals: cattle, sheep, horses, long bone metaphyses and vertebral bodies but skeletal lesions are rare.**	**Lesion morphology: lytic** **Humans: necrosis of affected long bones with sequestra but no periosteal bone formation or sclerotic repair, possible pathological fracture, lytic lesions affecting vertebrae may lead to collapse** **Animals: not much information but most likely the same as for humans, bone loss with little reactive bone response or repair**	**Humans: presence and size of sequestrum, posterior region of vertebrae can be involved, vertebral collapse leading to kyphosis is a potential feature so requires detailed consideration, no sclerotic repair** **Animals: presence and size of sequestrum, no periosteal new bone formation and no sclerotic repair**

4.4 Mycotic Infection

Mycotic infections are caused by fungus, which are predominantly soil-borne. Infection is usually through inhalation of the fungal spores leading to a primary pulmonary focus, which if disseminated may go on to involve the skeleton. The two main mycoses that need to be considered in the differential diagnosis of skeletal TB in humans and animals include: coccidioidomycosis (section 4.4.1) and blastomycosis (section 4.4.2).

4.4.1 Coccidioidomycosis

Coccidioidomycosis is primarily a respiratory disease of both humans and animals caused by the fungus *Coccidioides imitis* (Boden 2005:144). The disease is largely associated with dry and arid regions and is found in the southwest region of North America (including, most notably, California, Texas and Arizona) as well as parts of South America and Mesoamerica (Dungworth 1993: 668; Schwartz 2007: 328). Infection is initiated though the inhalation of fungal spores originally present in the soil. Desert rodents have been implicated as potential reservoirs of infection, shedding the fungal spores in their faeces (Dungworth 1993: 668). In addition to rodents, horses, deer, cattle, sheep, cats and dogs being susceptible to infection, so too are animals with compromised immune systems (Boden 2005: 144; Dungworth 1993: 670; Smith & Jones 1961:435). The infection can take two forms: an acute primary infection involving a self-contained focus within the lung or a chronic, more progressive disseminated form which involves

other soft tissues and the skeletal system (Aufderheide & Rodriguez-Martin 1998: 217-218). The disseminated form is rare in both humans and animals; in the latter it is most frequently observed in dogs, and less frequently in horses, cats and sheep (Dungworth 1993: 670; Aufderheide & Rodriguez-Martin 1998: 215). Any bone can be affected, although the mandible and ribs have been noted in particular (Siegel 1975: 30). In humans, it is reported that between 25% and 50% of disseminated cases involve the skeleton (Aufderheide & Rodriguez-Martin 1998:216; Ortner 2003: 326). Any bone can be affected, although the main skeletal elements targeted are the carpals and tarsals, followed by the vertebrae and ribs (Aufderheide & Rodriguez-Martin 1998: 216). There is also a noticeable predilection for lesions affecting the bony prominences of certain skeletal elements, including the radial and ulna styloid process, the coracoid processes and the acromion and humeral condyles (Ortner 2003: 327; Lignereux & Peters 1999: 346; Schwartz 2007: 328). The skeletal lesions or coccidioidal granulomas originate in the spongiosa, where they are extremely destructive. Eventually, the granuloma may penetrate the bone cortex, at which point new bone formation occurs (Zimmerman & Kelley 1982: 89). In animals, particularly dogs, osteomyelitis of the long bones can occur leading to lameness (Dungworth 1993: 670). Mandibular lesions similar in morphology to those observed in actinomycosis have also been reported (Siegel 1975: 30). In humans, osteomyelitis can also occur, but there is no sequestrum, which differentiates it from pyogenic osteomyelitis (Zimmerman & Kelley 1982: 90). When the vertebrae are affected, distinguishing the disease from TB is problematic,

especially as psoas abscesses can also develop (Fraser *et al.* 1951: 119-120). However, there are two main differences associated with coccidioidomycosis: the posterior parts of the vertebrae are involved and there is no vertebral collapse (Ortner 2003: 326). It must be emphasised that both humans and animals can suffer from more than one disease at any one time, a fact which further complicates the diagnosis of aetiology. Co-infection of TB and disseminated coccidioidomycosis is not unheard of, particularly in humans (see Fraser *et al.* 1951 for an example). Table 4.6 summarises the main skeletal predilection sites for this pathological condition.

Table 4.6 Differential Diagnosis: Coccidioidomycosis

Mycotic Infection (I): Coccidioidomycosis		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: any bone can be affected, but carpals, tarsals followed by the vertebrae and ribs most often affected. Bony prominences targeted: radial and ulna styloid process, coracoid process and the acromion and humeral condyles **Animals:** rodents, horses, deer, cattle, sheep, cats and dogs are susceptible any bone can be affected but ribs, mandible and long bones often affected (the latter in dogs)	**Lesion morphology:** predominantly lytic **Humans:** formation of granulomas in spongiosa, cortex may be penetrated leading to periosteal new bone formation, if vertebrae are involved, the posterior parts are often involved and formation of paravertebral abscess **Animals:** osteomyelitis may affect the long bones particularly in dogs, lesions similar to actinomycosis may affect mandible (swollen bone with lytic lesions)	**Humans:** posterior region of vertebrae can be involved, no vertebral collapse ***Be aware that TB and coccidiomycosis have been known to co-infect*** **Animals:** in articulated skeletons absence of vertebral lesions may eliminate MTB complex, levels of periosteal bone formation/sclerosis, in isolated bones osteomyelitis affecting limb bones would require careful consideration

4.4.2 Blastomycosis

Blastomycosis is a fungal disease caused by *Blastomyces dermatididis*. Like coccidioidomycosis, it primarily infects the lungs but can also progress to being systemic through haematogenous dissemination (Aufderheide & Rodriguez-Martin 1998: 214). Infection occurs in humans and animals, specifically dogs, although other species, including cats and horses, can also be affected (Dungworth 1993: 667; Lignereux & Peters 1999: 346). In addition to this, a rhesus monkey was diagnosed with disseminated blastomycosis, the first report of its kind in non-human primates (see Wilkinson *et al.* 1999). The fungal spores are soil-borne and infection is contracted through either inhalation or via a penetrating wound sustained near to a contaminated soil source (Zimmerman & Kelley 1982: 89), hence the reason this disease has been linked to the onset of agriculture (Schwartz 2007: 328). In dogs, the disease mainly affects larger breeds with the disseminated skeletal lesions commonly resulting in lameness (Boden 2005: 67; Dungworth 1993: 667). In humans, up to 50% of disseminated infections involve the skeleton, with some reporting 75% (Aufderheide & Rodriguez-Martin 1998: 214). In humans, any bone can be involved, but the prime predilection sites include: the thoracic and lumbar vertebrae, ribs, carpals, tarsals, skull and tibia (Ortner 2003: 326; Aufderheide & Rodriguez-Martin 1998: 214). Some skeletal involvement is associated with extension from a soft tissue focus, for example, the ribs (Aufderheide & Rodriguez-Martin 1998: 214.). The lesions are destructive with well-defined, sharp sclerotic margins (Schwartz 2007:328; Ortner 2003:326). In the post-cranial skeleton, the lesions may resemble osteomyelitis, with necrosis of affected

bone, in addition to periostitis in some cases (Aufderheide & Rodriguez-Martin 1998: 214). Skeletal involvement of the vertebrae resembles spinal TB in several ways: there is anterior erosion/lysis of the vertebral bodies, vertebral collapse on occasion (if the structural integrity is compromised), involvement of the intravertebral disk and the formation (in some instances) of paravertebral abscesses (Ortner 2003: 326; Aufderheide & Rodriguez-Martin 1998: 214). However, unlike spinal TB, the posterior parts of the vertebrae are commonly affected (Aufderheide & Rodriguez-Martin 1998: 214). Table 4.7 summarises the main skeletal predilection sites for this pathological condition.

Table 4.7 Differential Diagnosis: Blastomycosis

Mycotic Infection (II): Blastomycosis		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: any bone can be affected, mainly the thoracic and lumbar vertebrae, ribs, carpals, tarsals, skull and tibia **Animals:** any bone can be affected, specifically affects large breed dogs, also cats and horses, non-human primates (rhesus monkey)	**Lesion morphology:** predominantly lytic **Humans:** lesions in the post-cranial skeleton may resemble osteomyelitis, with necrosis, in addition to periostitis in some cases, destructive lesions well-defined with sharp sclerotic margins **Animals:** destructive lesions, may resemble osteomyelitis in post-cranial skeleton	**Humans:** resembles spinal TB, except for the involvement of the posterior regions of the vertebrae **Animals:** osteomyelitis affecting limb bones would require careful consideration regarding levels of periosteal bone formation and sclerosis etc

4.5 Neoplasia

The terms neoplasia or neoplasm literally translate as 'new formation' or 'new growth' (Baker & Brothwell 1980: 96; Aufderheide & Rodriguez-Martin 1998: 371). These abnormal growths/tumours are the result of uncontrolled tissue proliferation, and when affecting the skeletal system, may originate within any of the mesenchymal tissue that form the structure of bone, including the bone itself, the fibrous tissue, adipose tissue, cartilage, nerves or the blood vessels (Ortner 2003: 503; Thompson & Pool 2002: 263).

Although there are a number of identified carcinogens, the specific aetiology of most neoplasms is unknown (Baker & Brothwell 1980: 96). In animals, viral infections have been associated in some instances, but while suspected as the cause of some neoplasms in humans, certainty is lacking (Aufderheide & Rodriguez-Martin 1998: 373; Baker & Brothwell 1980: 96). Bone neoplasms are categorised as benign or malignant, depending upon morphology (Baker & Brothwell 1980: 96). It is the latter form, specifically osteosarcomas (section 4.5.1) and secondary metastatic bone tumours (section 4.5.2), that require consideration in the differential diagnosis of skeletal TB in humans and animals

4.5.1 Primary Malignant Bone Tumours: Osteosarcomas

Primary malignant tumours that originate within the medullary cavity of bone are rare in both humans and animals (Ortner 2003: 524, 532). However, where

they do occur, osteosarcomas are the most prolific example of this type of bone neoplasia, followed by chondrosarcomas (Ortner 2003: 524; Aufderheide & Rodriguez-Martin 1998: 377). In a 1957 survey of neoplasms in domestic animals, 7052 neoplastic tumours were observed, of which 169 were skeletal in origin. Of these, the overwhelming majority (n=138) were identified as osteosarcomas, and all but 13 cases affected dog (Smith & Jones 1957, as cited by Baker & Brothwell 1980: 99). In animals, osteosarcomas are the most prevalent form of bone neoplasia in dogs and cats, accounting for 80% of malignant bone tumours in dog and 70% in cat (Thompson & Pool 2002: 267; Jackson 1970: 127). As a result, the preponderance of information available related to the pathogenesis of bone neoplasia in animals is based upon the dog. This information, although informative, is based upon modern data, and therefore, may not be directly transferable to archaeological examples (Baker & Brothwell 1980: 100). It is well attested that certain larger breeds of dog appear predisposed to the development of bone neoplasia, including the following breeds: Great Danes, St. Bernards, Boxers, German Shepherds and Irish Setters (Thompson & Pool 2002: 267; Baker & Brothwell 1980: 100; Lignereux & Peters 1999: 346). This incidence has been postulated as being associated with weight and repeated metaphyseal trauma (Thompson & Pool 2002: 267; Baker & Brothwell 1980: 100). Unfortunately, little is known regarding the incidence rate for other animal species as osteosarcomas are seldom identified. However, Plumlee *et al.* (1993) do report upon a case of osteosarcoma in a cattle maxilla, stating that although

rare in larger species, when present it is usually identified within the skull region (Prumlee *et al.* 1993: 95).

Based upon the pathogenesis associated with dogs and humans, osteosarcomas can vary in their morphology from being predominantly osteolytic, osteogenic/proliferative or exhibiting a mixed pattern (Thompson & Pool 2002: 269). Unfortunately, these variants are also seen in other primary malignant tumours as well as in secondary metastatic tumours (Thompson & Pool 2002: 274). In dogs, the limb bones are most often affected, particularly the forelimbs with the distal ulna, proximal humerus and the metaphyseal region of the tibia and femur forming the main predilection sites (Baker & Brothwell 1980: 100). The joints are seldom affected (Thompson & Pool 2002: 275). In addition to the appendicular skeleton, the axial skeleton can also be targeted, with a 20-25% incidence rate reported in dogs (Thompson & Pool 2002: 268). The metaphyisis of the long bones are usually the focal point, although some tumours may form on the periosteum or even in other extraskeletal tissues (Palmer 1993: 133). In humans, osteosarcomas primarily affect younger individuals, more specifically adolescents and young adults, with a sex ratio of 2:1 in favour of males (Ortner 2003: 524). Osteosarcomas affect older individuals too and are often found associated with already abnormal bone, especially those involved in Paget's disease, for example, the mandible and cranium (Aufderheide & Rodriguez-Martin 1998:377). Osteosarcomas in younger individuals, however, are chiefly associated with areas of growth and as a result, the metaphyseal region of the

long bones, specifically the distal femur, proximal humerus and proximal tibia are most frequently involved (Aufderheide & Rodriguez-Martin 1998: 377; Ortner 2003: 524). The tubular bones of the hands and feet and the skull are less frequently affected (Ortner 2003: 524). Osteosarcomas tend to originate in the metaphysis where bone lysis ensues; in some cases the cortex is eventually perforated and the malignancy extends into the soft tissue (Ortner 2003: 524-5). In addition to the sometimes exuberant formation of tumour bone (disorganised woven or fibre bone) (Ortner 2003: 525), reactive bone formation is also a common occurrence due to involvement/irritation of the periosteum. A characteristic periosteal response observed in some cases of bone neoplasia is the formation of bony spicules varying in length with some reaching several centimetres aligned perpendicular to the bone cortex. This is described as 'sunburst' because of its striking appearance when viewed radiologically (Figure 4.6) (Aufderheide & Rodriguez-Martin 1998: 377-8; Ortner 2003: 525).

Figure 4.6 A mummified human humerus displaying a **'**sunburst' periosteal response as observed in some cases of bone neoplasia (Aufderheide & Rodriguez-Martin 1998: fig 13.3)

A characteristic sub-periosteal response is termed ‘Codman’s triangle’ or ‘angle’ and relates to a mass of reactive bone which reduces in width as its projects away from the cortex forming a triangular shape (Ortner 2003: 525; Thompson & Pool 2002: 275). There are many identified sub-types of osteosarcoma that are subject to specific schemes of classification both in modern veterinary and medical practice. One specific sub-type called ‘productive osteoblastic osteosarcoma’ can closely resemble osteomyelitis when the diaphyses of the long bones are affected (Thompson & Pool 2002: 271). The difference between a productive osteoblastic osteosarcoma resembling osteomyelitis and osteomyelitis lies in the presence or absence of a sequestrum, with the former characteristic of osteomyelitis (see section 4.2.3) (Aufderheide & Rodriguez-Martin 1998: 379). However, the difficulty arises when attempting to differentiate this from tuberculous osteomyelitis, which either possesses a very small sequestrum or none at all (section 4.2.3). Table 4.8 summarises the main skeletal predilection sites for this pathological condition.

Table 4.8 Differential Diagnosis: Primary Malignant Tumour (osteosarcoma)

Neoplasm (I): Primary Malignant Tumour (osteosarcoma)		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: younger individuals targeted (adolescents and young adults), metaphyseal region of the long bones (distal femur, proximal humerus and proximal tibia), can be found associated with Paget's disease in older individuals (skull) **Animals:** primarily dogs (large breeds), but also cats, axial skeleton can be involved but limb bones most often affected, particularly forelimbs (distal ulna, proximal humerus and the metaphyseal region of the tibia and femur), less frequently cattle (skull)	**Lesion morphology:** mixed **Humans:** lytic lesions originate in metaphysis, perforation of cortex, sometimes exuberant tumour bone and periosteal bone formation (spicules – sunburst effect), sub-periosteal response (Codman's triangle) **Animals:** *same as for humans*	**Humans:** *same as for animals* **Animals:** joints seldom affected, a productive osteoblastic osteosarcoma can closely resemble osteomyelitis when the diaphyses of the long bones are involved, key lies in the absence of a sequestrum in osteosarcoma

4.5.2 Secondary Metastatic Bone Tumours

Secondary metastatic involvement of the skeleton is more commonly observed in humans than primary malignant bone tumours (Ortner 2003: 537). The opposite is observed in animals, although this could be a reflection of potential cases not being actively sought upon identification of the primary focus (Thompson & Pool 2002: 312). Secondary metastatic bone tumours can affect both the appendicular and axial skeleton in humans and animals with the vertebrae most frequently affected in humans (Ortner 2003: 534), the ribs, vertebrae and proximal long bones most frequently affected in dogs and the distal limbs in cats (Thompson & Pool 2002: 312). Secondary metastatic tumours are generally osteolytic and can be difficult to differentiate from primary malignant bone tumours (Thompson & Pool 2002: 312). As secondary metastatic involvement is largely a result of haematogenous dissemination, cancellous bone forms the primary target. It is subsequently destroyed and sometimes completely replaced by tumour bone, resulting in destruction of the cortical bone (Ortner 2003: 535). In humans, when the vertebral column is affected, the thoracic vertebrae are the most frequently targeted. The vertebral body forms the primary focus, although the posterior regions can also become affected, which in some cases may result in compression fractures (Ortner 2003: 535). There are some key differences apparent when considering secondary metastatic involvement of the vertebrae and spinal TB. For example, if kyphosis is present in the former, it would be less acute than in spinal TB. In addition to this, the

posterior regions of the vertebrae are rarely involved in spinal TB and finally, individual non-contiguous vertebra can be affected in secondary bone neoplasia, unlike in TB (Aufderheide & Rodriguez-Martin 1998: 140-141). Table 4.9 summarises the main skeletal predilection sites for this pathological condition.

Table 4.9 Differential Diagnosis: Secondary Metastatic Tumour

Neoplasm (II): Secondary Metastatic Tumour		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: both appendicular and axial skeleton (thoracic vertebrae most often affected) **Animals:** primarily dogs (large breeds), but also cats, both appendicular and axial skeleton, the ribs, vertebrae and proximal long bones most frequently affected in dogs and the distal limbs in cats	**Lesion morphology:** lytic **Humans:** vertebral bodies targeted but also the posterior regions, may result in compression fracture **Animals:** lytic lesions with less periosteal new bone formation	**Humans:** if kyphosis is present, it would be less acute than in spinal TB, individual non-contiguous vertebrae can be affected, posterior regions affected also **Animals:** not much information, as rarely identified in the veterinary literature

4.6 Joint Pathology

There are many different types of joint pathology that can affect both humans and animals. These can be categorised in several ways but generally include those that are degenerative, work/activity related, traumatic, developmental/congenital, inflammatory and infective, as well as those whose aetiology is not yet certain. As presented in Chapter 3, TB predominantly targets the weight-bearing joints and the thoracic and lumbar vertebrae, leading in chronic cases to tuberculous arthritis in the appendicular skeleton and tuberculous spondylitis in the axial skeleton (specifically the mid-lower vertebral column). In terms of differential diagnosis, erosive and inflammatory joint pathologies require consideration. The most prominent include: septic arthritis (section 4.6.1), rheumatoid arthritis (section 4.6.2) and ankylosing spondylitis (section 4.6.3).

4.6.1 Septic Arthritis

Septic arthritis is an infection of the synovium that extends to affect the joint cavity and eventually the bone (Aufderheide & Rodriguez-Martin 1998: 106; Ortner 2003: 222). The aetiology of septic arthritis is non-specific but the causative agent is predominantly bacteria, the most prominent being *Staphylococcus aureus* (Aufderheide & Rodriguez-Martin 1998: 106). Infection occurs via haematogenous spread, penetrating injury or by direct extension from either a soft tissue or skeletal focus (osteomyelitis) (Ortner 2003: 222). Where

the latter occurs, it is sometimes impossible to identify whether the joint pathology was in fact primary or secondary (Baker & Brothwell 1980: 123). In humans, the knee and hip are the primary sites for infection (Figure 4.7) (Ortner 2003: 222). In animals, the knee (stifle), tarsal (hock) and metacarpophalangeal/metatarsophalangeal (fetlock) joints are most commonly affected by arthritis (Boden 2005: 385). However, any joint can become infected and sometimes simultaneously, particularly evident in cases of polyarthritis affecting neonatal animals (colloquially referred to as joint-ill) (Boden 2005: 384). In swine, this is often the result of infection with *Erysipelothrix rhusiopathiae* (Sokoloff 1960: 205) and in sheep and goats *Chlamydia psittaci* has been identified (Kaneps 1996: 216). Once infective agents gain access to the joint cavity, the synovial fluid is replaced with infective exudate and the articular cartilage is destroyed leaving the bones that form the joint exposed (Figure 4.8) (Baker & Brothwell 1980:123). Destruction of the bone takes the form of osteomyelitis, the result in some cases being ankylosis of the joint (Aufderheide & Rodriguez-Martin 1998:106; Ortner 2003: 222).

Figure 4.7 Human knee affected by septic arthritis with bony ankylosis (Ortner 2003: fig 9-51)

Figure 4.8 Horse sacrum with septic arthritis: extensive pitting and destruction of the joint surface (Baker & Brothwell 1980: fig 14)

It is very difficult to differentiate septic arthritis from tuberculous arthritis, especially in archaeological assemblages where no soft tissue survives (Ortner 2003: 222). In humans, tuberculous arthritis is described as being far more destructive and would result in a greater degree of limb shortening. In addition to this, ankylosis of the joint in TB would involve fibrous tissue as opposed to septic arthritis where union of the bones occurs (Rogers & Waldron 1995: 92). A potential TB diagnosis would be supported by the identification of extra-skeletal lesions, specifically affecting the vertebral column (Aufderheide & Rodriguez-Martin 1998: 107). In the absence of articulated remains in zooarchaeology, the differential diagnosis of an isolated example would have to include both septic arthritis and tuberculous arthritis (amongst others). Table 4.10 summarises the main skeletal predilection sites for this pathological condition.

Table 4.10 Differential Diagnosis: Septic Arthritis

Joint Pathology (I): Septic Arthritis		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: knee and hip are primary sites for infection **Animals: any joint but the knee (stifle), tarsal (hock) and metacarpophalangeal/metatarsophalangeal (fetlock) joints are predilection sites, sometimes simultaneous infection of several joints (polyarthritis) in neonatal animals**	**Lesion morphology: predominantly lytic** **Humans: lytic lesions affecting bones of the joint (osteomyelitis) with later ankylosis of joint** **Animals: *same as for humans***	**Humans: bony ankylosis of the joint, not fibrous as in TB, not as destructive as TB** **Animals: *same as for humans***

4.6.2 Rheumatoid Arthritis

Rheumatoid arthritis (RA) is a systemic inflammatory disease of the synovial joints affecting both humans and animals (specifically dogs) but is of unknown aetiology (Aufderheide & Rodriguez-Martin 1998: 99). In humans, women are most often affected (with a ratio of 3:1), with older middle-aged individuals primarily afflicted (Rogers & Waldron 1995:55-56). The disease is polyarticular, bilateral and symmetrical, targeting most notably the metacarpophalangeal and interphalangeal joints of the hands (Ortner 2003: 562; Aufderheide & Rodriguez-Martin 1998: 99). The joints of the feet are less frequently involved, along with, those of the axial skeleton, but other bones of the extremities, including the carpals, tarsals, humerus and ulna (shoulder and elbow joint) may be affected. The temporomandibular joint and the knee are also predilection sites (Ortner 2003: 562). Necrosis of the synovium and subsequent cartilage destruction exposes the underlying cortical bone to erosion (Figure 4.9). Along with macroscopic bone destruction, osteopenia and localised sclerosis would also be visible on a radiograph. Eventually, the affected joints become deformed with subluxation commonly affecting the metacarpophalangeal region. Some cases may terminate in fibrous ankylosis and later bony ankylosis (Aufderheide & Rodriguez-Martin 1998: 99). However, where joint mobility is retained, changes associated with degenerative joint disease may also manifest (Ortner 2003: 562).

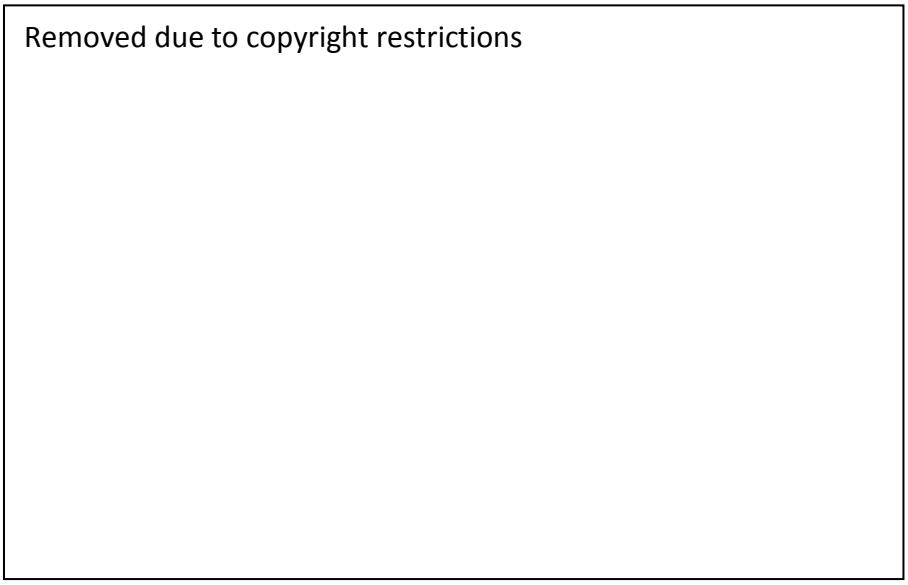

Figure 4.9 Rheumatoid arthritis affecting a human ulna displaying loss of cortical bone and exposure of trabeculae (Waldron 2009: fig 4.3)

Canine rheumatoid arthritis (CRA) has been reported in different breeds of dog, but predominantly smaller breeds and toy breeds (Palmer 1993: 178) leading to progressive lameness (May 1999: 750). It affects both males and females and onset is usually associated with middle-aged animals (May 1999: 750). As in humans, the disease is frequently polyarticular, bilateral and symmetrical with the distal limbs of the appendicular skeleton most often affected (May 1999: 750), specifically the small bones of the hands and feet (carpals and tarsals), along with the stifle and elbow joints (Palmer 1993: 178). In dogs, involvement of the bone is primarily erosive, including loss of mineralisation and marked erosion of the subchondral bone. However, subchondral sclerosis may also be visible on

radiographs, along with the formation of periarticular osteophytes around the joint margins (May 1999: 751). In progressive cases, joint deformity and subluxation will be a feature with fibrous ankylosis (Palmer 1993: 178)

Lack of definitive palaeopathological evidence has given rise to the perception that RA is a relatively modern disease, at least in humans (Rogers & Waldron 1995:54). Although there have been some tentative identifications made on archaeological remains (see Aufderheide & Rodriguez-Martin 1998:101), definitive diagnoses are problematic. This is undoubtedly due to a combination the extent of bone preservation and recovery techniques. Osteopenic bones are more prone to taphonomic damage (Rogers & Waldron 1995:58) and the smaller bones of the hands and feet are in some instances not recovered during excavation. Cases of RA cannot be reliably identified without the presence of lesions within the hands and feet (Rogers & Waldron 1995: 59), therefore, suspect lesions in another joint or an isolated joint would garner a number of potential differential diagnoses. Differentiating RA from tuberculous arthritis or any form of septic/infective arthritis is especially difficult (Aufderheide & Rodriguez-Martin 1998: 141). As the distribution of tuberculous arthritis is predominantly unilateral, in a fully-articulated skeleton, differentiation by extra-skeletal lesion distribution would be possible (Lignereux & Peters 1999: 341). However, in disarticulated bones, especially faunal remains, a list of potential differential diagnoses is the best that could be achieved. If the bone was identified as canid and the lesion affecting the joint was predominantly erosive,

then RA would be amongst the potential aetiologies. Table 4.11 summarises the main skeletal predilection sites for this pathological condition.

Table 4.11 Differential Diagnosis: Rheumatoid Arthritis

Joint Pathology (II): Rheumatoid Arthritis		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: older middle-aged individuals, metacarpophalangeal and interphalangeal joints of the hands, carpals, tarsals, humerus and ulna (shoulder and elbow joint) temporomandibular joint and the knee may also be affected, **Animals:** primarily middle – aged dogs (small breeds and toy breeds), small bones of the hands and feet (carpals and tarsals) along with the stifle and elbow joints	**Lesion morphology:** predominantly lytic **Humans:** polyarticular, bilateral and symmetrical, bone destruction, osteopenia, localised sclerosis, subluxation affecting metacarpophalangeal region, fibrous ankylosis and later bony ankylosis, joint mobility maintained (DJD may manifest as result) **Animals:** polyarticular, bilateral and symmetrical, mainly lytic, loss of mineralisation and marked erosion of the subchondral bone, subchondral sclerosis, formation of periarticular osteophytes around the joint margins, joint deformity and subluxation will be a feature along with fibrous ankylosis	**Humans:** polyarticular, bilateral and symmetrical **Animals:** in articulated skeletons, the presence of polyarticular, bilateral and symmetrical lesions would be key

4.6.3 Ankylosing Spondylitis

Ankylosing spondylitis (AS) belongs to a group of diseases called sero-negative spondyloarthritides (SpA) (Waldron 2009: 56). In humans, AS is inflammatory and progressive, primarily targeting the entheses (Aufderheide & Rodriguez-Martin 1998: 571). The aetiology remains unknown, although there is compelling evidence to suggest that it may be genetic and associated with the presence of a specific tissue antigen referred to as HLA-B27 (Rogers & Waldron 1995: 64; Aufderheide & Rodriguez-Martin 1998: 571). Males are more commonly affected, with the disease manifesting in the second and third decades (Ortner 2003: 571). The axial skeleton, specifically the sacroiliac joints and the vertebral joints, form the primary predilection sites with the elbow and hip joints of the appendicular skeleton also affected (Ortner 2003: 571). Pathological changes affecting the larger joints of the appendicular skeleton are impossible to differentiate from RA (Aufderheide & Rodriguez-Martin 1998: 103). However, changes to the axial skeleton, specifically the sacroiliac joint and vertebral column are more diagnostic. The disease is usually initiated within the sacroiliac joint, affecting both the synovial and ligamentous parts resulting in erosive lesions (most obvious on the iliac side) and terminating in ankylosis (Rogers and Waldron 1995:65; Aufderheide & Rodriguez-Martin 1998: 102). The characteristic appearance of AS in the vertebral column is described in some texts as 'bamboo spine' (see Rogers & Waldron 1995:65). This metaphor arises from the formation of enthesopathies at the point where the fibres of the

annulus fibrosus attach to the bodies of the vertebrae (Rogers & Waldron 1995: 65). This leads to the development of syndesmophytes that form bridges uniting the vertebral bodies. Further inflammation of the vertebral ligaments, specifically the anterior longitudinal ligament leads to widespread calcification, sometimes involving the costovertebral joints resulting in the vertebral column becoming a solid, rigid structure (Figure 4.10) (Aufderheide & Rodriguez-Martin 1998:103; Rogers & Waldron 1995: 65). The lack of subsequent vertebral movement results in osteopenia, in addition to the affected vertebrae remodelling to become more 'squared' in appearance, as a result of anterior erosion (Aufderheide & Rodriguez-Martin 1998:103). The difference between AS and tuberculous spondylitis in humans is the greater level of anterior vertebral destruction in cases of TB, resulting in collapse and angular kyphosis. Kyphosis can be a feature of AS in humans (Rogers & Waldron 1995:68), although in cases of spinal tuberculosis, the degree of collapse and kyphosis can be extremely acute. Similarly, erosion of the anterior vertebral bodies occurs in AS but this is not usually accompanied by cyst or abscess formation as in TB where the destruction is far more aggressive (Aufderheide & Rodriguez-Martin 1998: 141). Ankylosis of the sacroiliac joints can occur both in TB and AS, but in TB it is usually bilateral and the erosive lesions more destructive (Aufderheide & Rodriguez-Martin 1998:139).

Figure 4.10 Ankylosing spondylitis of the axial skeleton with fusion of the sacroiliac joints, vertebrae and a number of ribs (Waldron 2009: fig 4.5)

The characteristic pathological changes associated with ankylosing spondylitis (AS) in humans are also seen in animals, but the terminology associated with the latter differs in some texts. A similar condition involving ankylosis of the vertebrae in animals has been described as spondylosis deformans and ankylosis spondylosis – both indicating a degenerative aetiology. However, it has also been acknowledged that analogous changes may result from an inflammatory process, for example, diskospondylitis (Palmer 1993: 157). Varying nomenclature aside, the lesions associated with this disease are initiated by degeneration of the *annulus fibrosus* stimulating the production of new bone at the periphery of the

vertebral bodies and eventually leading to the ankylosis of neighbouring vertebrae, as in humans (Baker & Brothwell 1980: 129; Palmer 1993: 157).

One difference between the manifestation of the lesions in the axial skeleton in humans and animals is the lack of involvement of the sacroiliac joints in the latter (Sokoloff 1960: 229).The lesions are commonly identified in dogs, pigs and bulls (Palmer 1993: 157) but also in foxes (see Harris 1977) and horses (see Bartosiewicz & Bartosiewicz 2002; Stecher & Goss 1961). In bulls, the lesions have been associated with or, at least exacerbated by, their reproductive duties It is stated, however, that any older animal is expected to develop lesions (Figure 4.11) (Palmer 1993: 157).

Figure 4.11 Ankylosing spondylitis of the lumbar vertebrae in a bull (Palmer 1993: fig 1.129)

In older horses, the lesions have been associated with repetitive strain and riding (Bartosiewicz & Bartosiewicz 2002: 819), although lesions have also been observed in immature horses and associated in some cases with developmental problems, disease or trauma (Stecher & Goss 1961:254-255). An adult horse aged between 8-9 years and dating to the 7th century AD was identified as having 17 contiguous vertebrae fused together (T8-L6), one of the most extreme cases reported (Figure 4.12) (Bartosiewicz & Bartosiewicz 2002:821). As in humans, differentially diagnosing these vertebral lesions from those associated with an infection of TB would be largely focused upon the scale of destruction. Table 4.12 summarises the main skeletal predilection sites for this pathological condition.

Figure 4.12 Ankylosing spondylitis of 17 contiguous vertebrae in a 7th century AD horse (Bartosiewicz & Bartosiewicz 2002: fig 2)

Table 4.12 Differential Diagnosis: Ankylosing Spondylitis

Joint Pathology (III): Ankylosing Spondylitis		
Primary Predilection Sites	**Lesion Morphology**	**Criteria for Differential Diagnosis**
Humans: axial skeleton, (sacroiliac joints and the vertebral joints), elbow and hip joints of the appendicular skeleton also affected **Animals:** often termed spondylosis deformans and ankylosis spondylosis, dogs, pigs, bulls, foxes, horses	**Lesion morphology:** Proliferative **Humans:** impossible to differentiate from RA in larger joints, erosive lesions affecting sacroiliac joint terminating in ankylosis, vertebral column: anterior erosion, formation of enthesopathies, then syndesmophytes unite the vertebrae, ossification of vertebral ligaments, 'bamboo spine', vertebral osteopenia, 'squared' appearance **Animals:** ***same as for humans*** except no involvement of sacroiliac joint	**Humans:** kyphosis can be a feature but it is <u>not</u> acute and there is no collapse of vertebrae, no abscess or cyst formation, less destructive, ankylosis usually not bilateral in TB **Animals:** ankylosis in horses in particular can affect high numbers of contiguous vertebrae (not in MTB Complex), less destruction

4.7 Conclusion

This overview of differential diagnosis in relation to skeletal TB in humans and animals serves to illustrate how challenging a methodological process this is. The fact that bone can only react to injury, insult and infection in a limited number of ways ensures that the determination of aetiology, even in articulated skeletons, is by no means straight-forward. This is a factor that is compounded in disarticulated zooarchaeological assemblages, where the majority of isolated lesions are non-specific. As a result, differential diagnosis in zooarchaeology is not a regular and standardised practice. However, as highlighted above, there are subtle differences in bone response to different types of disease, which enables the short-listing of possible aetiologies. This list will be longer and less specific when regarding an isolated lesion, but the creation of a list (however long) nonetheless represents a more structured approach, and one which would allow for later data comparisons. The main differences between those specific diseases and conditions are presented in tables throughout the text. These user-friendly tables represent an attempt to initiate the development of a broad framework of reference for differential diagnosis in zoopalaeopathology. In this instance, skeletal TB is the focus; however, this is something that through further research and refinement of methods will hopefully be repeated for other diseases.

5. AVENUES OF ZOONOTIC INFECTION IN THE PAST

'Nature is opportunistic, so whenever a new niche is created, emergent and old diseases will inevitably seek to exploit the new opportunities'

(Baum & Bar-Gal 2003: 73)

5.1 Introduction

The Neolithic revolution heralded a turning point in history; a catalyst for social change that came at a price – disease. Plant and animal domestication changed the hunter into a farmer, the hunted into livestock and a nomadic lifestyle into sedentary subsistence. The relationship between humans and animals was now based upon management and control. Pathogens were provided with the ideal environment in which to adapt and become established. Diseases were to flourish, affecting both humans and animals and zoonoses became a consequence that still exists today.

5.2 Avenues of Zoonotic Infection

The avenues of infection associated with zoonotic pathogens and their spread between humans and animals are outlined below. The ways in which these are manifested on rural settlements in the Iron Age and Viking Age will be expanded upon here. Conditions in the past would not have been too dissimilar to those still apparent in developing countries today. The presence of a reservoir of infection,

when combined with an absence of knowledge, awareness and control measures, would provide a zoonotic disease with ample opportunity to infect new hosts.

Mycobacterium bovis is a zoonotic pathogen, possessing a wide host range (section 3.3). As a result there are numerous pathways of infection between different species of mammal and also between humans and other mammals (Figure 5.1).

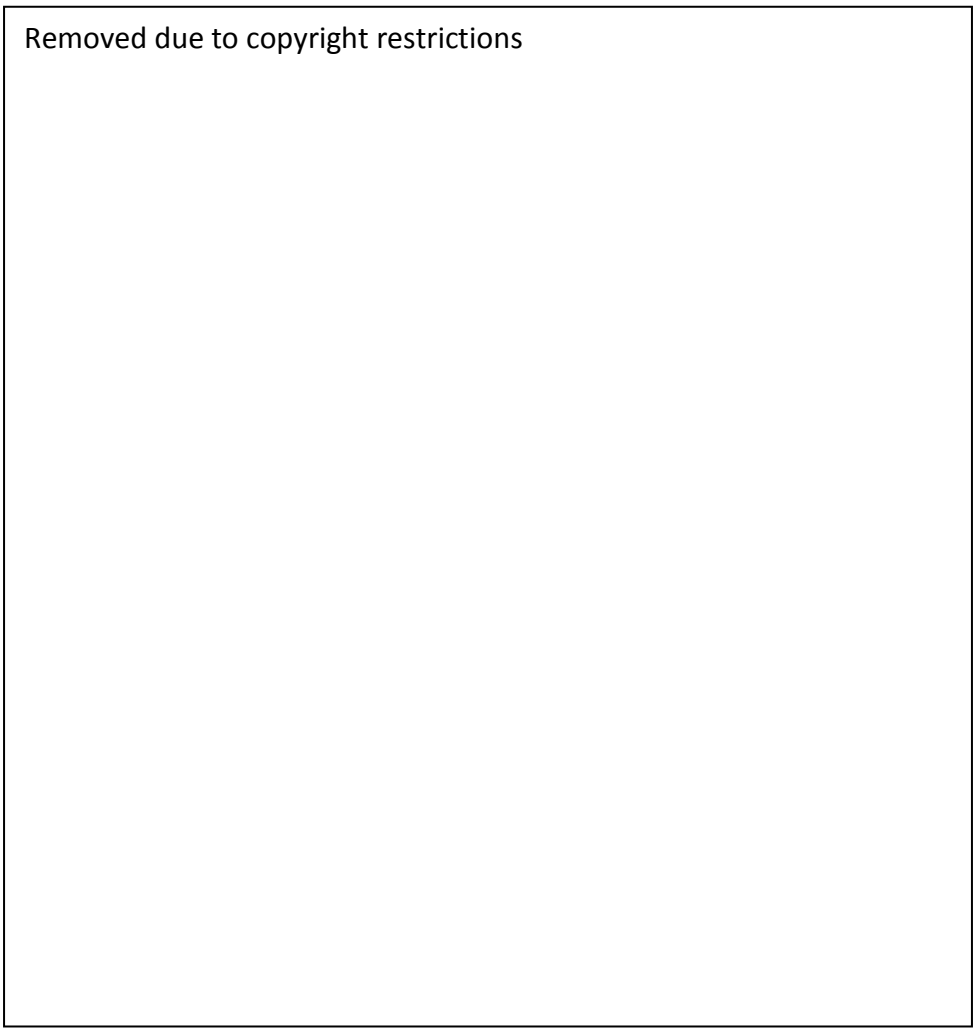

Figure 5.1 Pathways of infection associated with *M. bovis* in different host types (Biet *et al.* 2005: Figure 3)

The two primary pathways for the zoonotic transmission of *M. bovis* are ingestion and inhalation, although transmission could also occur cutaneously, through injury and breaks in the skin (Etter *et al.* 2006: 69). The consumption of infected dairy products, specifically milk is considered the main route for zoonotic infection in humans (Cosivi *et al.* 1998: 65). In the past, its frequency in the young led to its consideration as a disease of children (O'Reilly & Daborn 1995: 4). The characteristic swelling of the cervical lymph nodes was called scrofula (section 3.14.1). The consumption of raw and poorly cooked meat could also potentially cause infection in humans (Roberts & Buikstra 2003: 76). Another primary avenue of zoonotic infection between humans and animals is the inhalation of infected aerosols (Etter *et al.* 2006: 64). Infected humans can also infect animals through the contamination of their bedding or hay with waste products, for example, urine (O' Reilly & Daborn 1995: 4). Animals in close contact with infected farm workers and veterinarians can also contract the disease. One study reported upon the infection of 114 cattle from 16 different herds as a result of contact with 12 people suffering from the disease (Schliesser 1974 as cited by Roberts & Buikstra 2003: 77).

On a settlement site in the Iron Age and Viking Age, transmission of zoonotic infections such as *M. bovis* may have taken place either directly or indirectly (Figure 5.2). Direct routes of infection would involve the consumption of contaminated food products, specifically poorly cooked or raw meat and infected milk (Cosivi *et al.* 1998: 65-67). However, it has been suggested that the use of primitive cooking pots made from porous ceramics may harbour infection (Cohen & Crane-Kramer 2003: 88). Therefore, food products free from infection may become contaminated

through re-use of a vessel that had previously housed infected material. In addition to direct ingestion, close contact with an excreting animal may also lead to inhalation of infected aerosols. Like humans suffering with pulmonary infection, cattle also cough emitting infected bacilli into the air (Etter *et al.* 2006: 64).

Indirect transmission would involve contact with infected by-products resulting in either inhalation or cutaneous transmission. For example: contact with infected water sources, inhalation of dust particles infected with excreted aerosols (Biet *et al.* 2005: 418), butchering carcasses, working hides and bone, the use of urine and dung, an animal bite (Corner 2006: 309) or the presence of an open wound (Etter *et al.* 2006: 69).

Cattle urine is reportedly used in some developing countries to wash utensils and render wall and floor surfaces when mixed with soil to form a paste (Roberts & Buikstra 2003: 76). Stale urine is also used in textile production and has been identified in Viking Age sediments in Iceland (see Milek 2006: 291). Dung is also used in developing countries today for building materials, as fuel and also to fertilize soil (Roberts & Buikstra 2003: 76-77). In the past, there is evidence to indicate the fertilisation of soils using a wide range of organic waste (midden material), animal dung and in some cases human excrement (night soil or town-dung) (see Simpson *et al.* 1998: 123; McKenzie 2006: 82; Guttmann *et al.* 2006). Geoarchaeological analysis of the anthropogenic soils identified at the multi-period settlement site at Tofts Ness, Sanday, Orkney, revealed that the manure used was largely human in origin, with some evidence for pig faeces (Bull *et al.* 1999: 553; Mckenzie 2006: 41).

The dangers in terms of disease associated with the use of both human and animal excrement as manure was reviewed by Santamaria and Toranzos (2003). There is also widespread historical and geoarchaeological evidence for the use of household waste, general midden material and even hides and skins as fertiliser (see Guttmann *et al*. 2006; McKenzie 2006: 99). In some areas, instead of adding these materials to soils, there is evidence in the form of ard marks illustrating that existing middens were ploughed and cultivated. Evidence for this exists at Jarlshof (Dockrill & Bond 2005: 24; Wooding 2005: 137) and Old Scatness, Shetland, in addition to Tofts Ness, Sanday, Orkney (Guttmann *et al.* 2006: 87).

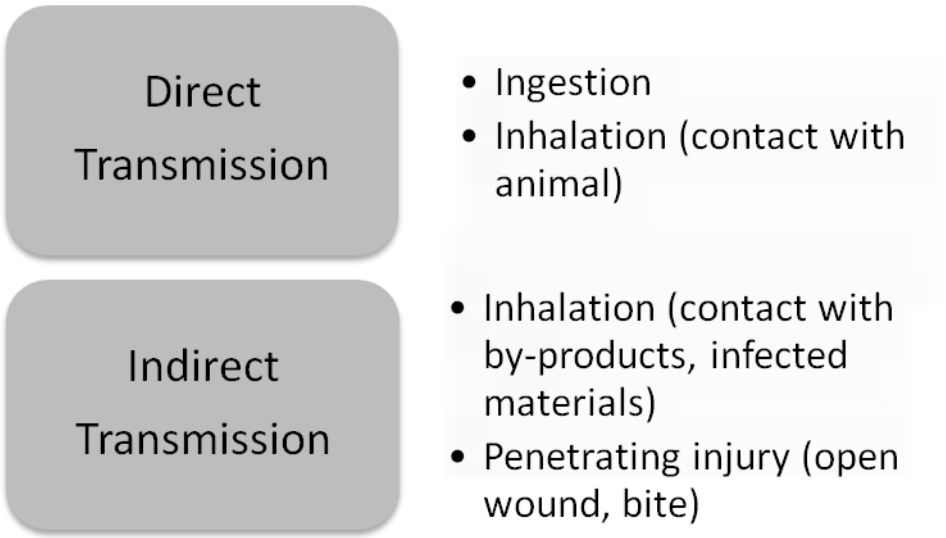

Figure 5.2 Direct and indirect routes of infection on rural settlement sites

5.3 The Iron Age and Viking Age/Norse

The Iron Age in southern Britain and the Viking Age and later Norse in the North Atlantic form the basis of this research. They represent different cultures and their

mutual study provides an interesting contrast; however, they also share a common factor, both were built upon economies dependent on agriculture and animal husbandry and as such, were subject to the same risks associated with zoonotic infection. The following sections provide a succinct overview of these two periods in time, highlighting those aspects of lifestyle and settlement that would have encouraged the establishment of zoonotic disease in rural settlements, in addition to presenting the existing evidence for the presence of MTB complex. Specific factors associated with each period have been selected and emphasised in their relation to the potential for zoonotic disease transmission or the potential evidence for disease presence. For the Iron Age, these include: the evidence for milk consumption, specifically dairying and breastfeeding (section 5.4.4) and the burial of articulated animal remains (ABGs) (section 5.4.5). For the Viking Age/Norse, this includes: the movement of peoples and animals (section 5.5.4). Although TB is described as an 'urban' disease and a disease of poverty in many texts (Roberts & Buiskta 2003, see Ortner 2003) because of its devastating tendency to thrive in densely populated areas, it is particularly important to emphasise as Cohen and Crane-Kramer do that the origins of this disease are, in fact, rural, '...*the rise of large population centers connected by transport permitted the maintenance of a number of density-dependant diseases, many of which first emerged as zoonotic infections...*' (Cohen & Crane-Kramer 2003: 89).

5.4 The Iron Age in southern Britain: Settlement, animal husbandry and zoonoses

The Iron Age in southern Britain '*...marked a turning point in British History'* (Cunliffe 2004: 117). This period in history dating between *c.* 800/700 BC – AD 43 reflects a time of change, but also of stability. This change did not occur over night; landscape division, the appearance of permanent and diverse settlement types and the adoption of a structured agricultural regime had its origins in the Later Bronze Age (Haselgrove 1999: 113). The culmination of this gradual transformation led to complex and varied settlement patterns, socio-economic development, the delineation of tribal regions, the formation of intricate hierarchical systems and the founding of tribal elites, the latter reported on by Julius Caesar (Bewley 1994: 93) and finally, the establishment of a trade and exchange network that had fluctuated from the Neolithic onwards (Mays & Taylor 2003: 194). This network was most apparent along the southern and eastern coasts and is supported by the discovery of assorted prestige metal artefacts (weapons, jewellery) and ceramics signifying connections with the La Tène and Hallstatt cultures of France and Germany (Haselgrove 1999: 131; Cunliffe 2004: 16). Although an island separated from the rest of continental Europe, Britain, in particular, was by no means isolated. Where there is contact, there is the opportunity for the introduction of disease. Zoonotic diseases like *M. bovis* would have been ideally suited to the more permanent settlement lifestyle and reliance on animal husbandry evident in southern Britain at this time. As Mays and Taylor stated in relation to the existing trade networks '*These contacts would doubtless have facilitated the spread of disease*' (Mays &

Taylor 2003: 195), and there is evidence to suggest the presence of MTB complex in continental Europe as early as the Neolithic (see Canci *et al.* 1996).

5.4.1 Settlement evidence

The evidence for Iron Age settlement, especially in southern Britain is abundant and demonstrates the presence of a diverse and varied settlement pattern and series of communities (Haselgrove 1999: 113). Archaeological investigations have identified cropmarks and surviving structures associated with several different settlement types (Haselgrove 1999: 113). These range from large hillforts and oppida to open settlements and smaller, more isolated farmsteads. For the most part, these are associated with habitation (Haselgrove 1999: 113). These settlement types differ in size and function but share a common theme - a close relationship between the community and their livestock. Some roundhouses, either previous dwellings or purpose-built, ancillary structures may have served as animal pens (Hambleton 1999: 1; Pope 2007: 219) and the uniquely shaped 'banjo' enclosures may also have served an animal husbandry purpose, with some hypothesizing a corralling function (Hambleton 1999: 1). However, there is also evidence for the potential presence of animals within the main dwelling area. The peripheral areas of the internal roundhouse are cited as having several probable functions, including most prominently storage and sleeping. However, it is also suggested that provision was made for the stalling of animals in these areas too (Pope 2007: 217). Soil phosphate analysis lends support to this interpretation. In some roundhouses (see Kelly 1988) changes in phosphate intensity has been noted across the internal floor space

indicating that the central floor areas were cleaned. This is in direct contrast to some of the peripheral areas that may have housed livestock (Pope 2007: 219).

In mainland Europe, specifically Denmark, where longhouses as opposed to roundhouses were the building tradition at this time, there is structural evidence for the sharing of domestic space (Sørenson 2007: 329). The longhouses were organised to incorporate animal stalls at one end as in some of the Viking Age longhouses (section 5.5.1) (Figure 5.3).

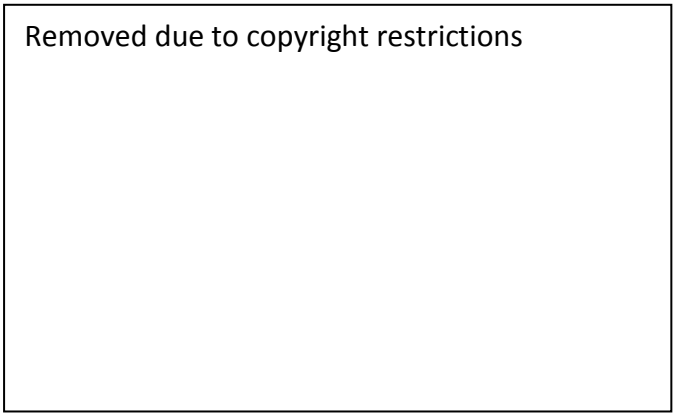

Figure 5.3 Danish longhouse illustration displaying animal stalls (Copenhagen Museum, Photo: Author)

Definite evidence for the presence of humans and animals under the same roof was discovered during the excavation of the early Iron Age longhouse of Nørre Tranders, Denmark. A fire destroyed the byre end of the longhouse and eighteen animal and five human victims perished in that part of the structure. The animals included: seven cattle, two horses, five sheep, two lambs, a suckling pig and a puppy (Sørenson 2007: 331).

5.4.2 Animal husbandry

Animal husbandry in Iron Age Britain was influenced by several different factors as highlighted by Hambleton (1999: 41-60): geographical region, topography, geology and settlement type. However, in general, the main focus was centred upon the three main domesticates, cattle, caprines and pig, with the latter the least frequent of the three (Haselgrove 1999: 115; Maltby 1996: 20). In addition to this, horses, dogs and domestic fowl were also kept, but evidence suggests there was little supplementation from wild resources (Haselgrove 1999: 115). Over time, a change in the species ratios (especially apparent in southern Britain) becomes evident, with a notable preference for sheep over cattle (see Albarella 2007). One hypothesis put forward for this increase implicates population expansion and resultant agricultural intensification (Albarella 2007: 394-5). This change is associated with a marked increase in arable farming (Hambleton 1999: 87). The importance of sheep manure should not be underestimated in this process. As Serjeantson highlights, sheep manure is of a better quality compared to cattle and pig dung, especially for cereal cultivation. If the sheep are allowed to graze elsewhere in the day and brought down to the fields at night, the manure is enhanced with additional plant nutrients (Serjeantson 2007: 83). Another hypothesis for the increase in sheep relative to cattle is associated with social re-organisation and the economy. The extra expense of keeping cattle may have increased their value as status symbols and indicators of wealth leading to a general reduction, except at high status settlements (Albarella 2007: 395). In the early Iron Age, the faunal evidence would suggest that sheep were generally valued greatly for their by-products, specifically wool, although the use of their milk must not be underrated (see Serjeantson 2007). The evidence for

cattle suggests a more varied utilisation (Maltby 1996: 21-23). However, there are regional differences in terms of preference and use of primary and secondary products, influenced by those factors highlighted at the beginning of this section (Maltby 1996: 90).

5.4.3 The Presence of MTB complex in Iron Age Britain

There is no evidence for a specific, normative burial rite in Iron Age southern Britain, although some have argued that the predominant burial rite was excarnation in the earlier and middle Iron Age (see Carr & Knüsel 1997) and cremation in the later Iron Age (Haselgrove 1999: 123; Carr 2007: 444) The formal burial of human remains is reportedly rare (Carr 2007: 444), however, there are exceptions, for example: the large inhumation cemetery at Wetwang Slack, East Yorkshire (section 6.6.1), the smaller more isolated inhumations at Barton Field, Tarrant Hinton (section 6.6.2) and inclusions of human remains in pits at Danebury Hillfort (section 6.6.3). Where inhumations have been excavated, information has been collected allowing for a better understanding of health in the Iron Age (see Good 2005; Redfern 2005; King forthcoming). The presence of MTB complex in Iron Age southern Britain has been confirmed through biomolecular analysis. Whether the disease was indigenous to Britain or had been introduced via the existing trade and exchange network cannot be ventured, but it was definitely present in the Iron Age human population. It was present prior to the Roman invasion and also predates similar finds by at least 300 years (Mays & Taylor 2003: 193). The Iron Age site at Barton Field, Tarrant Hinton, located in Dorset, yields the earliest case of this disease currently identified in Britain (see Mays & Taylor 2003). Fifteen skeletons

were found in association with a 'small agrarian settlement'. The particular skeleton found to be positive for MTB complex dates to the Middle Iron Age (400-230 BC) (Mays & Taylor 2003: 189). The skeleton was sampled for aDNA analysis and *Mycobacterium tuberculosis* was identified as the causative strain using PCR methods (Taylor *et al.* 2005: 2239). Although, the specific strain identified was not *M. bovis*, the confirmation of MTB complex in this Iron Age skeleton is compelling and strongly suggests that this disease was present in southern Britain. It is unlikely to represent an isolated example. Although there has been no identification of *M. bovis* within the human or contemporary animal populations from this period within the UK, the presence of the human strain at Barton Field, Tarrant Hinton, lends supports to the notion that the bovine strain was also present. This is especially in light of the biomolecular identification of *M. bovis* in four Iron Age human skeletons excavated in Siberia indicating zoonotic transmission (see section 3.12.6).

5.4.4 Milk Consumption in the Iron Age: Avenue of Infection

The analysis of faunal assemblages is not the only way to learn about animal husbandry practices in the Iron Age. Extensive lipid analysis of ceramic vessel fragments has revealed evidence for the presence of dairy fats providing direct evidence for milk production. Copley *et al.* (2005) present results that confirm dairying at four Iron Age sites in Britain, including: Maiden Castle, Danebury Hillfort, Stanwick and Yarnton Cresswell Field (Copley *et al.* 2005: 485). The analysis of two hundred and thirty-seven pottery vessels concluded that the milk derived from '*a variety of ruminant sources*' (Copley *et al.* 2005: 489). This is supported by the

zooarchaeological faunal data presented above (see Hambleton 1999; Albarella 2007 for overview).

The consumption of infected milk products is a primary avenue of infection for bTB, commonly manifested as cervical adenitis (a general term for swelling of the lymphs nodes) (scrofula), particularly in the young (section 3.14.1). The evidence for dairying in prehistory (see Copley *et al.* 2003; Copley *et al.* 2005), specifically the Iron Age in this case, illustrates the potential for zoonotic transmission of diseases. An isotope study by Jay *et al.* (2008) demonstrates this potential through breastfeeding practices at Wetwang Slack, East Yorkshire. A total of thirty-four infants less than six years of age from the Iron Age cemetery at Wetwang Slack were sampled for a nitrogen and carbon (Jay *et al.* 2008: 2). The results indicate that the infants sampled were not exclusively breastfed (Jay *et al.* 2008: 19). There appears to have been supplementation to this early diet of breast milk in the form of '*animal milk and/or plant gruel*' (Jay *et al.* 2008: 336). This illustrates that for some of the young at Wetwang Slack, the practice was to wean early, a pattern associated with increased fertility and population increase. Although the results from the Wetwang Slack isotope study does not directly indicate the presence of bTB, the results do display the use/dependence upon animal by-products in later prehistory and also indicates the potential for this disease (if present in the animal population) to be transmitted to the young at a very early age. Macroscopic lesions suggestive of gastro-intestinal TB are present in an individual from Wetwang Slack (section 3.12.5). The practice of early weaning may also have predisposed the young at Wetwang Slack to infection and illness. The consumption of breast milk and its

associated impact on health and well-being is well documented, especially the protection it affords against infection in early life (Lawrence & Lawrence 2004: 501). Therefore, the early cessation of breastfeeding or the reduction of breast milk consumption may have made the young at Wetwang Slack more susceptible to highly infectious illnesses, such as bTB particularly if products were being consumed from infected animals.

There is also the potential for TB to be directly transmitted between mother and infant during breastfeeding. If the mother is suffering from TB mastitis or has lesions associated with the breast, bacilli can be transmitted during feeding (Lawrence & Lawrence 2004: 504, 510). Even if lesions are not associated with the breast, a tuberculous mother with active pulmonary infection could infect her child through droplet infection associated with close contact (Lawrence & Lawrence 2004: 510).

5.4.5 Associated Bone Groups (ABGs): Ritual or rubbish? Or disease?

'*Animal burials are more an exception than a norm.*' (Bartosiewicz 2002: 33). The Iron Age is characterised by the presence of articulated animal burials. Articulated and semi-articulated animal skeletons have been excavated from various archaeological sites, most notably, Danebury Hillfort (section 6.6.3), where a number of 'special animal deposits' were identified (Grant 1984a). Animal burials have also been excavated at Garton Slack (West Yorkshire) (Noddle 1979) and Viables Farm (near Basingstoke, Hampshire) (Millett & Russell 1982). Some burials

are complete, with others just represented by a limb or a cranium (Hill 1995: 14). Debate as regards the nature of these animal deposits continues with some referring to them as 'special animal deposits' and associating them with ritual, whereas others appear inclined to believe they were just rubbish (Hill 1995: 13-15) (see Morris 2008a). Morris provides an excellent overview of this topic of study in his doctoral thesis entitled *Re-examining Associated Bone Groups from Southern England and Yorkshire, c.4000BC to AD1550* (Morris 2008a). In the literature, there is a varying nomenclature related to the labelling of such deposits. Some refer to them as 'animal burials' but more recently and to avoid any misinterpretation in meaning, the term 'articulated/associated bone groups' (ABGs) has been more widely adopted (Morris 2008a: 2-3). The reasoning behind these depositions of animals or animal parts is a continuing subject for debate in zooarchaeology (see Grant 1984a, 1984b; Wilson 1992, 1996; Hill 1995, 1996; Morris 2008a, 2008b). The title of Hill's BAR publication *Ritual and Rubbish in the Iron Age of Wessex* (Hill 1995) illustrates this perspective nicely. However, it is another category of interpretation that is of particular interest to this research, 'functional'. Functional is a descriptive term employed by Morris in his doctoral research to categorise interpretations that do not fit 'ritual' or 'rubbish'. These include death due to disease, death due to natural causes, pit falls and culling (Morris 2008a: 320). These 'functional' interpretations have been primarily directed at complete animal skeletons based upon the lack of butchery evidence. For example, death due to disease and deliberate burial for the purposes of disease containment has been an interpretation put forward by a number of analysts in association with complete articulated remains. In relation to the articulated animal skeletons excavated at

Wetwang Slack (section 6.6.1), Scott in her unpublished summary report stated '*The fact that they had not been exploited as food may indicate that they had died of disease, and their burials may have been an attempt to stop the spread of infection and suppress smells which would have attracted foxes and other unwanted scavengers*.' (Scott n.d). Other researchers, however, have been adamant that animal burials do not indicate death due to disease, including most notably Barbara Noddle who stated the following in relation to the animal burials located at Garton Slack; '*The burials were deliberate interments placed in properly excavated graves and not the dumping of a carcass, or a group of bones in a hole. Prehistoric man was too careful with his food supply to bury carcases in the ground unless for ritual purposes; at the very least fallen stock would be fed to the dogs. Only in modern times were stock buried, or burnt because of the threat of disease...therefore no animal protein was wasted. Without question the burials had some ritual significance, but what it was is impossible to deduce with any certainty. What is certain the animals were not buried by the Iron Age farmers because they were fallen stock*' (Noddle 1980: 767). Noddle and Scott, both reporting on animal burials from essentially the same site (Wetwang Slack and Garton Slack) shared very different opinions in relation to the potential explanation for the burial of complete articulated carcases. To be fair, the ABGs at Wetwang Slack were more randomly positioned in the landscape (section 9.5.4), whereas, those at Garton Slack appeared more deliberately positioned, with three associated with an infant cemetery (Brewster 1980: 310; Noddle 1980: 768).

In the absence of an obvious manner of death, factors that would appear to rule against the burial of an animal due to disease include: the digging of deliberate graves, the location of these graves (not simply just where the animals fell), the deliberate positioning of animals in the graves, sometimes as at Danebury Hillfort, in association with other animals and artefacts, for example, sling stones (Grant 1984b: 222). In addition to this, these ABGs often do not reflect a representative portion of the herd population expected as a result of natural mortality (Morris 2008b: 3). As Grant highlights at Danebury hillfort, sheep were the most frequently identified of the domestic species and pig the least. However, pigs were represented more frequently as ABGs (Grant 1984b: 223). In addition, horse and dog are not normally well-represented in the general domestic assemblages in relation to the three main domestic species, however, in the majority of cases they are the most frequent ABGs identified (Grant 1984b: 223). Clearly, as the evidence suggests, there is more to the burial of complete animals than just disease. However, it cannot be completely ruled out that some animals were buried due to disease in the Iron Age as Noddle so categorically states. It is also extremely likely that some diseased animals were buried for ritual reasons, either because their disease status was unknown or purposefully ignored.

Pathological lesions were observed in two Iron Age horse skeletons located in southern Britain (see Bendrey *et al.* 2008). The horses were excavated from pit features at two sites, Viables Farm, Basingstoke, Hampshire and Downlands, Walmer, Kent (Bendrey *et al.* 2008: 1582). The differential diagnosis of the lesions in both horses included both TB and brucellosis. Unfortunately, the aDNA analysis was

inconclusive, so no definitive diagnosis could be made. The lesions associated with both animals were advanced and suggestive of systemic bacterial disease in both cases. It was interpreted that they have been obviously diseased and unfit for work (Bendrey *et al.* 2008: 1589). Therefore, it is interesting to see how these fit into the 'ritual or rubbish' debate as regards their burial, or perhaps rather deposition complete in pits. The horse excavated at Viables Farm, Basingstoke, was associated with human remains and other animal skeletons suggesting a possible ritual reason for deposition. As Bendrey *et al.* stated; '*Inclusion of a diseased horse in this deposit may therefore have been a pragmatic decision that did not have a high economic cost to the inhabitants of the site*' (Bendrey *et al.* 2008: 1589). The legs of the second horse at Downlands, Kent, however, displayed evidence for having been broken after death – presumably to fit the animal within the pit. Bendrey argues that this suggests that the purpose behind this particular deposition was the disposal of a sick animal, and possibly an attempt to contain infectious disease (Bendrey *et al.* 2008: 1589); so 'rubbish' or 'functional' disposal as opposed to 'ritual'.

There is historical evidence to support the notion that people in the past were aware of the dangers of consuming diseased animal flesh, so the burial of diseased animals as a control measure is not a radical concept. According to the entries within the *Talmud* dating to the 2nd and 5th centuries AD (Steele & Ranney 1958: 908), if an animal upon slaughter displayed lesions that were located between the pleura and lungs, then they were deemed unfit for consumption (Wight 1942: 237). The burial of animal carcases as a result of disease is, therefore, a valid

interpretation and should not be dismissed. However, the fact remains that without an obvious disease-related manner of death, the deposition of complete animals with no evidence for the removal of meat could arguably be the result of animal sacrifice as opposed to the non-consumption of diseased flesh (Morris 2008a: 320). However, who is to say that 'ritual' and 'functional' practices were not combined for economic purposes? If an Iron Age farmer had an animal that was not thriving, it would make more economic sense to sacrifice this animal. It has been suggested that the selection of horses and dogs for sacrifice may have been based upon economic reasoning. As Grant stated, '...*when we come to examine the species involved, the possibility arises that many of the animals sacrificed are not those that are the most vital to the well-being of the community.*' (Grant 1984b: 222) and '*Thus if a society wished to make a sacrifice for any reason....a horse may have been more easily spared than a cow, a sheep or a pig.*' (Grant 1984b: 223). The same would surely apply to sickly animals – although not in all cases. In his writings entitled *On Sacrifices,* Lucien of Samosata, a Syrian who lived between c. AD 125-180, stated the following in relation to animal sacrifice by the Greeks: '*The victims are accordingly brought forward – an ox from the plough, a ram or a goat, according as the worshipper is a farmer, a shepherd or a goatherd; sometimes it is only frankincense or a honey cake; nay a poor man may conciliate the God by merely kissing his hand. But it is with the priests that we are concerned. They first make sure that the victim is without blemish, and worthy of the sacrificial knife....*' (Lucian, *On Sacrifices*, translated by Fowler & Fowler 2008: 256).

5.5 The Viking Age/Norse in the North Atlantic: Settlement, animal husbandry and zoonoses

The Viking Age and later Norse settlement period represents a time dominated by movement and the colonisation of new lands. Whether this was governed by political unrest, over-population, trade or an insatiable thirst for exploration and the riches that could be plundered, or all of these from time to time, are irrelevant in the context of this research. Geography, however, is important; leaving Scandinavia and travelling westwards, the islands of Shetland, Orkney, the Faeroes, Iceland and Greenland formed a fortuitous series of stepping-stones across the North Atlantic, guaranteeing not only the passage of humans and their animals, but also and inevitably, of disease.

The islands of the North Atlantic were colonised by Scandinavian settlers between 800-1000AD (McGovern 1990: 331). This initial occupation is termed *landnám* and literally means 'land-taking' (Smith 1995: 319). The Scottish Islands (Shetland and Orkney) were colonised in c.800AD, followed by the Faeroes in the mid-ninth century (Ritchie 1993: 11), Iceland between 870-930AD and Greenland in c.980AD (Helgason *et al.* 2000: 697; Magnusson 2000: 132,143,151). The expansion westwards reached as far as eastern Canada and North America (McGovern 1990: 331).

Figure 5.4 Westward expansion across the North Atlantic (Fitzhugh 2000: 13)

5.5.1 Settlement evidence

The *Sagas* provide detailed and entertaining accounts of the westward Viking expansion across the North Atlantic, but they are ultimately second-hand (some compiled hundreds of years after the written events). As is the case with any literary account, they necessitate caution in their use (Stoklund 1984: 98,100). However, the settlement evidence that exists provides a primary source of information which, when supplemented with the available historical literature, can provide a greater understanding of the everyday lives of those new settlers and the types of buildings they lived in.

There have been numerous Viking Age buildings identified and excavated across Iceland (see Milek 2006 for overview). In her doctoral thesis, Milek identified 46 residential buildings that had been subjected to excavation and could be dated with confidence to the Viking Age (Milek 2006: 14). The distribution pattern of these is subject to some bias though and is seemingly a product of a series of combined factors, such as: visibility, repeated investigation of areas mentioned in the *Sagas*, research excavations (for example, the collaborative NABO project entitled: 'Landscapes of Settlement in North East Iceland') and rescue excavations focused in and around Reykjavik as opposed to a true representative pattern.

The migrating Scandinavian colonisers took with them characteristic building traditions, which have been identified all over the North Atlantic (Stoklund 1984: 98). The primary residential building type in the early stages of colonisation consisted of one large room divided into three sections or distinct spaces. The central section was comprised of three aisles with benches lining the inner side of each wall, facing a centrally located hearth (Stoklund 1984: 98; Milek 2006: 98) (Figure 5.5). This type of building, which varied in size, has been referred to as a 'skáli', which literally translates to 'hall' in English (Milek 2006: 88). Other descriptive labels include: 'fire-house' and 'fire-halls' (Milek 2006: 88).

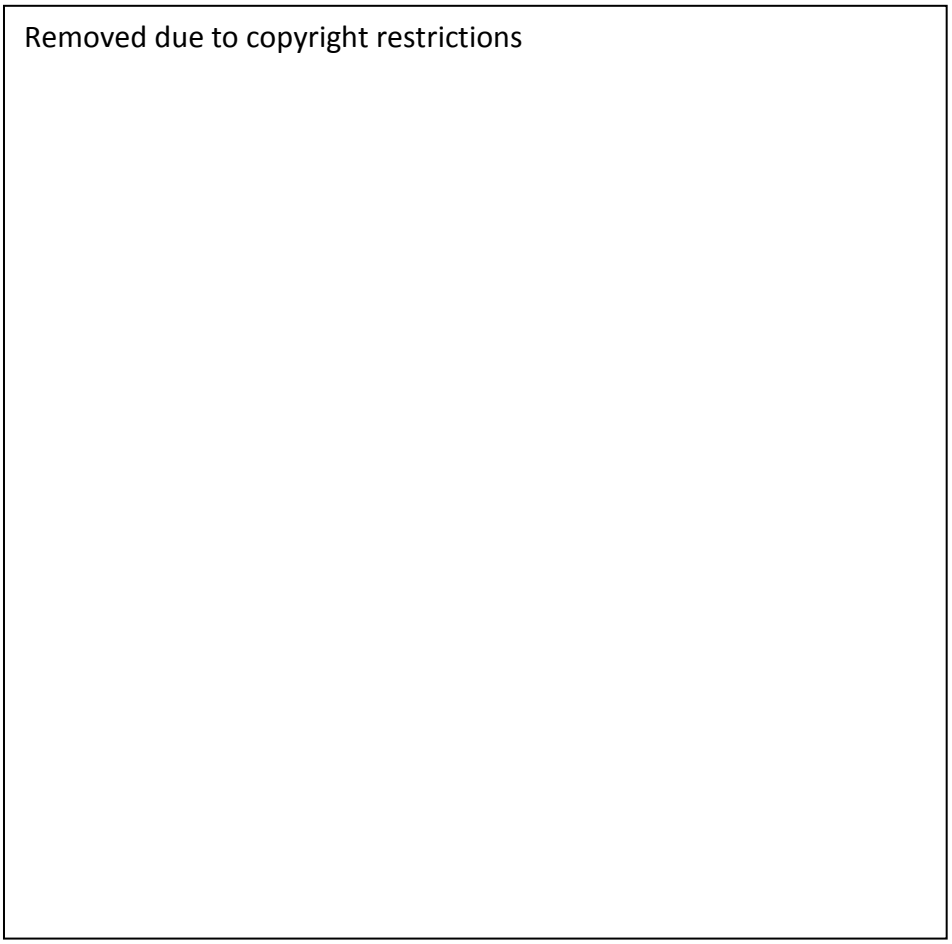

Figure 5.5 Skáli excavated at Kvívík, Faeroes (Adapted from Stoklund 1984: Fig 43)

These relatively simple early dwellings were often associated with a number of outbuildings, together comprising the farmstead. These outbuildings would certainly have included a byre for the livestock (Milek 2006: 88).

Over time, archaeological investigation of these buildings has found that the basic 'skáli' blue-print, although integral to the settlement type, was subjected to

customisation, with some long-standing structures possessing a multitude of phases. Additional rooms (annexes) were added to some structures, these have been identified archaeologically as later additions to the main building, for example, at Stöng, Iceland (Figure 5.6), although the question of how much 'later' these additions were made is difficult to discern (Milek 2006: 97). These additions did not follow a universal pattern and differed in size and function both within Iceland itself and also the other islands of the North Atlantic (Milek 2006: 97, 98).

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Figure 5.6 Skáli at Stöng with later additions and plan (Stoklund 1984: Fig 55; Photo: Author)

The later structural phases associated with the Viking Age settlement at Jarlshof, Shetland, also displays change over time. However, this change unlike those in Iceland, brought humans and animals into direct contact with one another. In the early phases at Jarlshof, a simple 'skáli' structure existed with a number of separate ancillary structures functioning as a byre/barn, bathhouse and smithy (Ritchie 1993: 66-7). Later in the 11th century, a 'true longhouse' was formed with the addition of a byre to the main living area (Figure 5.7). As Ritchie stated, '*not only did the presence of cows add to the warmth of the house, but the fumes from their urine*

protected the humans from respiratory diseases' (Ritchie 1993: 35). Ironically, if the cattle were infected with a zoonotic disease, the urine (amongst other things) would instead of 'protecting' against respiratory infection, be the likely cause.

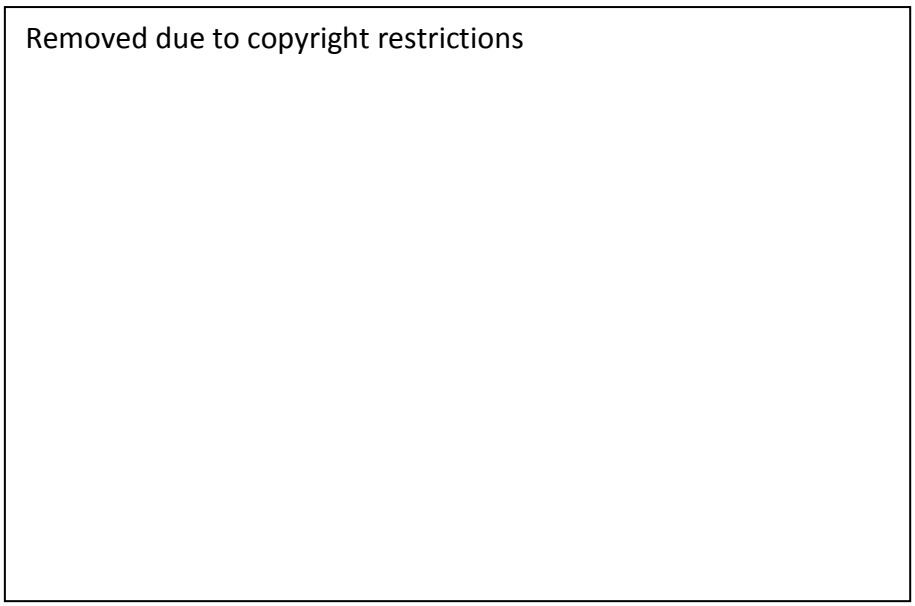


Figure 5.7 Jarlshof 'Longhouse' with integrated byre (Ritchie 1993: fig. 51)

The residential building types that incorporated a byre at one end, referred to as longhouses, were a tradition not practised in Iceland (Milek 2006: 90). Longhouses of this type were identified in the Iron Age across parts of mainland Europe (Milek 2006: 90), for example, Denmark (section 5.4.1). In the Viking Age, they were present in parts of Scandinavia (Milek 2006: 90) as well as in Shetland. Although there is no suggestion for such integration in Iceland, there is still evidence for the presence of animals and animal waste within the domestic living areas, providing the potential for zoonotic transmission of disease.

Milek conducted a multi-disciplinary analysis of a number of Viking Age residential buildings in Iceland in order to elucidate further the use of space within these structures. Excavations at Aðalstræti 14-18, Reykjavik, in 2001 revealed the remains of a skáli dating to the 10th Century. A series of post-holes and stake-holes were observed in the northwest corner. These were positioned at right angles to the western wall and were suggestive of a specific/specialised function (Milek 2006: 163). Micromorphological analysis of the sediments in this area revealed the presence of trampled herbivore dung and plant material. In addition, very small fragments of bone were also found embedded within the sediment, along with a high proportion of fungal spores (Milek 2006: 179-180). Combining the archaeological and geoarchaeological evidence, this area was subsequently interpreted as the location of a series of animal stalls, probably housing sheep or goats. The presence of the small bone fragments were interpreted as inclusions in human waste, leading to the conclusion that this area was also used on occasion as a human lavatory (Milek 2006: 180) (Figure 5.8). The close proximity of human waste and animals also provides a potential avenue of infection for the animals if the humans were infected. Human to animal disease transmission is not unheard of (section 5.2). Phylogenetic analysis reveals that the human form of TB emerged prior to the bovine from, suggesting that the disease transmission pathway may have been from humans to bovines, rather than the other way around (Brosch *et al.* 2002).

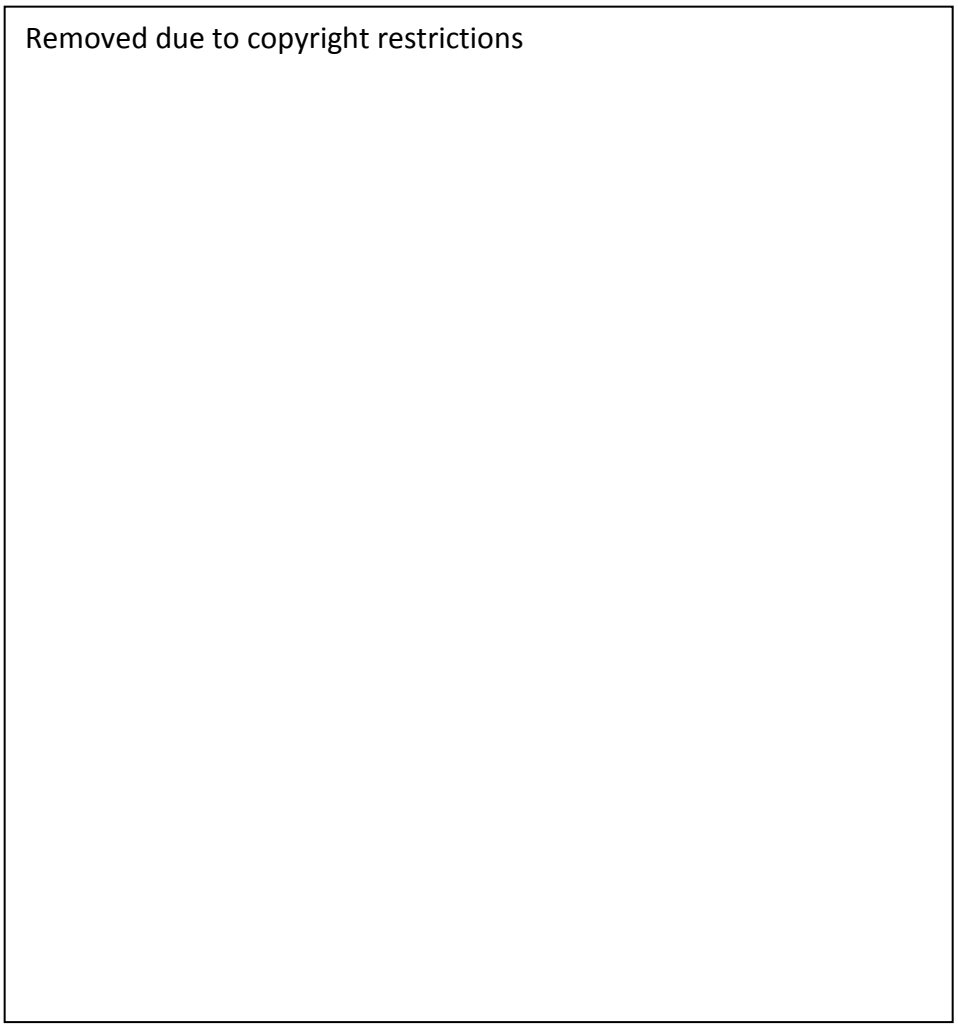


Figure 5.8 Plan of Aðalstræti 14-18, highlighting the location of animal stalls in the north-western corner (Milek 2006: Figure 4.42)

5.5.2 Animal husbandry

The pattern of animal exploitation across the North Atlantic is broadly similar and adheres to the following trend: in order of frequency, cattle, caprines and pig predominate, supplemented by marine and wild animal resources (Ritchie 1993:

36). The ratio of specific species (both wild and domestic) across the North Atlantic during this time, as in the Iron Age, is dependent on a number of factors, the most prominent including: site location and environmental conditions. At Jarlshof, Shetland, Hamilton (1956: 137) interpreted the faunal evidence as being suggestive of an early Norse economy based largely upon domestic livestock and cereal cultivation, with a change in the later phases to a higher dependence on coastal resources, with seal, in particular, being heavily exploited. This trend of a later increase in marine resources is also apparent at the site of Sandwick and may represent a regional trend for Shetland (Bigelow 1992: 19). This evidence for a later intensification in fishing is also visible in Orkney, at the Brough of Birsay settlement site (McGovern 1990: 338). Due to the unsuitable nature of the climate in the Faeroes, the economy was largely livestock-based and focused upon cattle and sheep (Haywood 1995: 90). A thorough overview of the zooarchaeological evidence in Iceland as it stood in the mid 1990s is provided by Amarosi (1996). More recently, a series of research excavations associated with the North Atlantic Biocultural Organisation (NABO), in addition to excavations conducted by Fornleifastofnun Íslands (Institute of Archaeology, Iceland), have added, and continue to add, to our understanding of this period in Icelandic history. For example, the three Icelandic sites (Hofstaðir, Hrisheimer and Sveigakot) analysed as a part of this research and associated with the *Landscapes of Settlement in North East Iceland* project all possess substantial zooarchaeological assemblages. Sheep were dominant at all three sites, followed by cattle and pig (sections 9.9, 9.10 and 9.11). These three main domesticates, in addition to horse have been described as the '*landnám* package' in association with Iceland (Amarosi 1996: 469). The same

pattern of species ratios was also observed at Westness, Rousay, Orkney (section 9.8). Cattle and caprines were universally valued for their primary and secondary products across the islands of the North Atlantic, but again these patterns vary from site to site as emphasised by Einarsson (1995: 121) in relation to the Icelandic evidence: '*…different farms placed varying emphasis on the individual supplies of food – livestock, game and marine resources*'. Faunal assemblages from the Norse settlement site of Bornais on South Uist suggest an emphasis on meat production (Mulville 2005: 190), whereas in Iceland there was an emphasis placed in later times on dairying and the production of *skyr*, an Icelandic dairy product (Byock 2001: 47).

5.5.3 The Presence of MTB complex in the Viking/Norse North Atlantic

Early Scandinavian evidence for TB is reported in a Neolithic passage grave at Rössberga, Sweden (see Nuorala *et al.* 2004; Nuorala 2004: 24) and also in a 2500-1500 BC human female recovered in Denmark (see Møller-Christensen 1983). Mycobacterium Tuberculosis (MTB) Complex was identified using biomolecular methods in the Late Viking/Early Medieval site of Björned, North Sweden (Nuorala 2004: 25). Therefore, it is clear that MTB Complex was present in Scandinavia, as well as other parts of Europe (section 1.3). Tuberculosis was macroscopically identified in the indigenous Pictish population at Westness, Rousay, Orkney (section 9.8) (see Sellevold 1999) and is also one of a number of differential diagnoses in three Viking Age females excavated at Hofstaðir, Iceland (section 9.9) (see Gestsdóttir 2009; Gestsdóttir pers. comm.). Further macroscopic identifications of TB were also reported in three Viking Age/Norse humans excavated at Hrísbrú,

located in the Mosfell Valley, Iceland (see Walker *et al.* 2004). Two of these identifications are based upon the presence of sub-periosteal rib lesions alone. Although these lesions are associated with respiratory infection, they are non-specific (section 3.12.3) and as such TB is only one of a possible number of differential diagnoses. The remaining example consists of a lytic lesion, affecting the base of the skull described as a 'brain abscess' (Walker *et al.* 2004: 3). No other lesions were noted in each skeleton and crucially no vertebral lesions were identified. Therefore, without biomolecular confirmation, these macroscopic identifications must be viewed with caution. However, the evidence from this site and Hofstaðir would suggest that TB was, in all likelihood, present in Viking Age Iceland.

5.5.4 The movements of peoples and animals: avenue of infection

The movement and immigration of peoples and animals into new previously 'unsettled' landscapes[1] or 'virgin land' (Stoklund 1984: 97), particularly focusing on the Faeroes and Iceland, provided ample opportunity for the introduction of disease. Family groups moving westwards had limited knowledge of their destinations but took livestock with them to form self-sufficient homesteads/settlements (Figure 5.9). In reference to a Norwegian Viking called Flóki Vilgerðarson, it was reported in *Landnámabók* (Book of Settlement) that *'He*

[1] It has been stated in various texts and in the *Íslendingabók* that Irish priests had settled in Iceland and the Faeroes prior to the influx of new settlers between 870-930AD. However, no evidence has yet been found to support their presence there (Richards 2005: 100; Haywood 1995: 90).

took livestock with him, for he planned to settle permanently.' (Magnusson 2000: 132).

Figure 5.9 Animals being transported across the North Atlantic (Rosing 2000: 5)

The Viking colonisation of the Scottish Isles was almost certainly conducted by individuals of Scandinavian heritage, however, the islands that followed would undoubtedly have included second and third generation settlers, possessing mixed Scandinavian, English, Scottish and Irish (Gaelic) heritage (Haywood 1995: 87). Modern DNA analysis of Icelanders supports this view. Helgason *et al.* 2000 conducted a study on the variation of di-allelic and microsatellites associated with the Y-chromosome in a sample group of individuals including: Scandinavians, Icelanders and Gaels from both Scotland and Ireland. The results of this study indicated a mixed ancestry supporting the view that the majority of founding males in Iceland were of Scandinavian origin and the majority of females possessed Gaelic ancestry, originating from the British Isles (Helgason *et al.* 2000: 697, 715). More

recent stable isotope research on archaeological human remains conducted by Price and Gestsdóttir (2006) also demonstrates evidence for migrant settlers. A total of 90 Viking Age burials were sampled for strontium isotope analysis and 9-13 of these were identified as not being native to Iceland (Price & Gestsdóttir 2006: 140).

Therefore, it is clear that in the Viking Age, there was substantial movement and contact with neighbouring islands and communities. This provided the perfect opportunity for the spread and introduction of infectious disease across the North Atlantic. However, it is not just humans that were mobile, livestock were also subject to transport across the North Atlantic, providing additional means for potential infection. This is especially pertinent considering the voyage would have seen them confined in close quarters for days and possibly even weeks in some cases; a journey that would have been highly stressful for an animal, potentially compromising its immune system and leaving it vulnerable to disease and illness. A study conducted on the immune status of mature cattle steers (*Bos indicus)* in Australia, specifically focussing on the effects of transportation, concluded that the stress of this movement led to the lessening in number of leukocytes along with decreased leukocyte function, leaving the animals susceptible to infection. Leukocyte levels and function returned to normal within six days (Stanger *et al.* 2005: 2632, 2635). Studies have also been conducted on pigs with similar results (see McGlone *et al.* 1993).

The movement of animals by people from one location to another is recognised as far back at the Neolithic in southern Britain. Recent strontium isotope research by

Viner *et al.* (2010) on thirteen cattle teeth from the Neolithic site of Durrington Walls revealed that eleven of these were not local to the area, with some surmised as having travelled at least 100km (Viner *et al.* 2010: 1,7). Towers *et al.* (2010) presented similar strontium isotope results associated with the analysis of cattle teeth from two early Bronze Age barrows also in southern Britain. A single tooth from each site was identified as not being local to the area (Towers *et al.* 2010: 508), again demonstrating the moving of livestock. The reasons behind the movement of animals are largely irrelevant in the context of this research; the fact that livestock were being moved over great distances, however, displays the potential for the spread of disease to different regions and other animals and, potentially, also to humans. One might also suspect that similar movements among people might contribute to similar adverse health effects.

In reference to the colonisation of the North Atlantic by the Vikings, as far as the researcher is aware there have been no published isotopic studies on the *landnám* faunal assemblages in Iceland to ascertain the animals' place of origin. However, it must be assumed that, as with the diverse ancestry of the Icelandic colonisers, the animals would have originated not only from Scandinavia but also from the British Isles, Scottish Isles and possibly even the Faeroes. The fact that the Vikings briefly made contact with North America has also been highlighted in association with the potential introduction of TB to some areas on the eastern coast of North America. As Gómez i Prat and Mendonça de Souza state: *'An intriguing point in paleoepidemiology of tuberculosis in prehistoric North America is that most of the cases of tuberculosis are dated from the second millenium, after the Vikings with*

their domesticated cattle settled in colonies on the Eastern Coast. According to written documents they exchanged goods, including cow milk, with Indian groups, and this fact forces us to consider the possible penetration of European strains of mycobacteria in North America previous to the XV century' (Gómez i Prat and Mendonça de Souza 2003: 158). Therefore, the movement of animals and people in the past undoubtedly played a very important role in the dissemination of disease, a role that has been largely neglected in an archaeological context, but one that if explored, could be potentially illuminating.

5.6 Conclusion

The study of the Iron Age in southern Britain and the Viking Age/Norse settlement period in the North Atlantic, specifically Orkney and Iceland, provides the opportunity to explore the potential environments in which a zoonosis like bTB could potentially thrive. These periods in time are dominated by the close relationship shared between humans and their animals, whether it involved sharing the same domestic space, travelling across the sea together or simply the use of animal products and by-products from dairying, hide and wool use, and manure for fertilizer. The avenues of infection on both these types of rural settlement mirror each other and, although transmission would not be based purely on density and household numbers, the constant presence of animals and humans in close contact would enable pathogens to remain active. Even if the humans and animals became resistance to the pathogen, the living conditions and factors highlighted above would ensure that when the opportunity arose, for example, a compromised immune system, the pathogen would adapt and take advantage. These periods in

time, therefore, form the ideal ‘target’ periods from which to search for and identify bTB in faunal remains.

6. MATERIALS: SETTING THE SCENE

6.1 Introduction

This chapter focuses on the materials that form the basis of this research. Materials, in this instance, relates to those modern and archaeological faunal assemblages selected for analysis. The time periods and geographical regions chosen for study are presented along with the reasoning behind their choice (section 6.2 & 6.3). This is followed by an outline of the parameters identified to aid the selection process of sites and assemblages (section 6.4), a description of the modern material selected (section 6.5) and a detailed review of the archaeological sites and their corresponding faunal assemblages chosen for analysis (sections 6.6 & 6.7).

6.2 Time periods

The Iron Age (c.800/700BC – AD43) in England and the Viking Age/Norse in Orkney (c.800AD – 11th Century) and Iceland (c. 870-930AD – 11th Century) were selected for study. The selection of these time periods was based upon the evidence for settlement types, husbandry patterns, animal management and lifestyle indicators, as discussed in Chapter 5. In combination, these were such that a zoonotic disease like bTB could be expected to thrive in both animal and human populations, spread through close contact and be introduced to new lands through migration and immigration.

6.3 Geographical regions

The decision to focus on England in the Iron Age was based upon its diverse settlement evidence. The Iron Age English landscape comprised settlements ranging from densely populated hillforts to small, isolated farmsteads (section 5.4.1). There were no urban centres in the Iron Age, but the hillforts housed hundreds of people and livestock (section 6.6.3). The Iron Age in England, therefore, provides a valuable opportunity to study the impact of this disease in a pre-urbanised, rural society possessing dense communal settlements, on the periphery of well-established trade routes across Continental Europe. The North Atlantic region, specifically the islands of Orkney and Iceland in the Viking Age, were selected because they were at the centre of a wave of migrations, travel and trade westwards from Scandinavia. People and their animals from Norway and other parts travelled across the North Atlantic using the small islands of the Northern Isles, Faeroes, Iceland and Greenland as fortuitous stepping stones across a challenging stretch of sea. The Viking expansion westwards is well documented both archaeologically and textually, with the islands of Orkney and Iceland heavily featured. The North Atlantic region, therefore, provides the opportunity to study the spread and introduction of zoonotic disease to new lands, and in the case of Iceland, virgin lands.

6.4 Sites and assemblages: Selection parameters

The selection of sites and assemblages in England followed two defined parameters:

- The presence of associated bone groups (ABGs)

The study of ABGs, where possible, is important for two reasons: a potential motive for burying an animal in its entirety is disease; and secondly, a complete animal skeleton (if found to be pathological) allows for the observation and recording of skeletal lesion patterning.

- The presence of contemporary human populations with MTB Complex disease (either confirmed through biomolecular techniques or suspected through osseous lesions)

Skeletal evidence for MTB Complex disease in a contemporary human population (especially if identified as bovine in origin) would be strongly suggestive of its presence in the corresponding faunal population.

The following additional parameter was identified for the selection of sites and assemblages in Iceland:

- The analysis of archaeological faunal remains from *landnám* settlement sites

The targeting of faunal assemblages from the earliest Viking settlements, especially in previously unsettled virgin lands like Iceland, carries with it the potential to pinpoint the introduction of diseased stock and, therefore, the movement of zoonotic disease across the North Atlantic.

6.5 Modern material: Defining criteria

In addition to the analysis of archaeological material, modern faunal remains displaying pathological change suggestive of bTB were sought for examination and biomolecular sampling. The aim of this was to formulate diagnostic criteria using modern pathological examples that would hypothetically possess better pathogen DNA preservation. In the first instance, pathological badger skeletons were targeted for analysis because: a) bTB is a known problem in the UK badger population and the disease process is not impeded by the regular slaughter of sick animals as in the case of domestic cattle and b) a high number of badgers are found as roadkill and become a part of zooarchaeology reference collections. Enquiries were also made to various veterinary universities, archaeological units and freelance zooarchaeologists. The only substantial modern collection of pathological faunal remains obtained for analysis was the Baker Collection, curated at the University of York. Table 6.1 summarises the modern material obtained for analysis, its location and the format in which it was available for study.

Table 6.1 Modern material obtained for analysis and sampling

Species	Skeleton or Disarticulated	Location	Format Available for Analysis	MTB Complex (Suspected/Confirmed Prior to Analysis)	Sampled for bacterial DNA? (Y/N)
Badger (*Meles meles)*	Skeleton	Cambridge University	Skeleton loaned	Suspected	Y
Badger (*Meles meles)*	Skeleton	Wessex Archaeology	Skeleton loaned	Suspected	Y
Red Deer (*Cervus elaphus)*	Skeleton	University of Oxford	Skeleton visited	Suspected	Y
Pig (*Sus scrofa domestica*)	Partial Skeleton	Grosvenor Museum, Chester	Skeleton visited	Suspected	Y
Baker Collection (mixed assemblage)	Disarticulated	The University of York	Assemblage visited	Suspected	Y

6.6 Archaeological sites and assemblages: Iron Age

The following three sites were selected for study from England: Wetwang Slack, East Riding of Yorkshire (section 6.6.1), Barton Field, Tarrant Hinton, Dorset (section 6.6.2) and Danebury Hillfort, Nether Wallop, Hampshire (section 6.6.3) (Figure 6.1). The following sub-sections provide a synopsis of each site, illustrating the reasoning behind their selection for study.

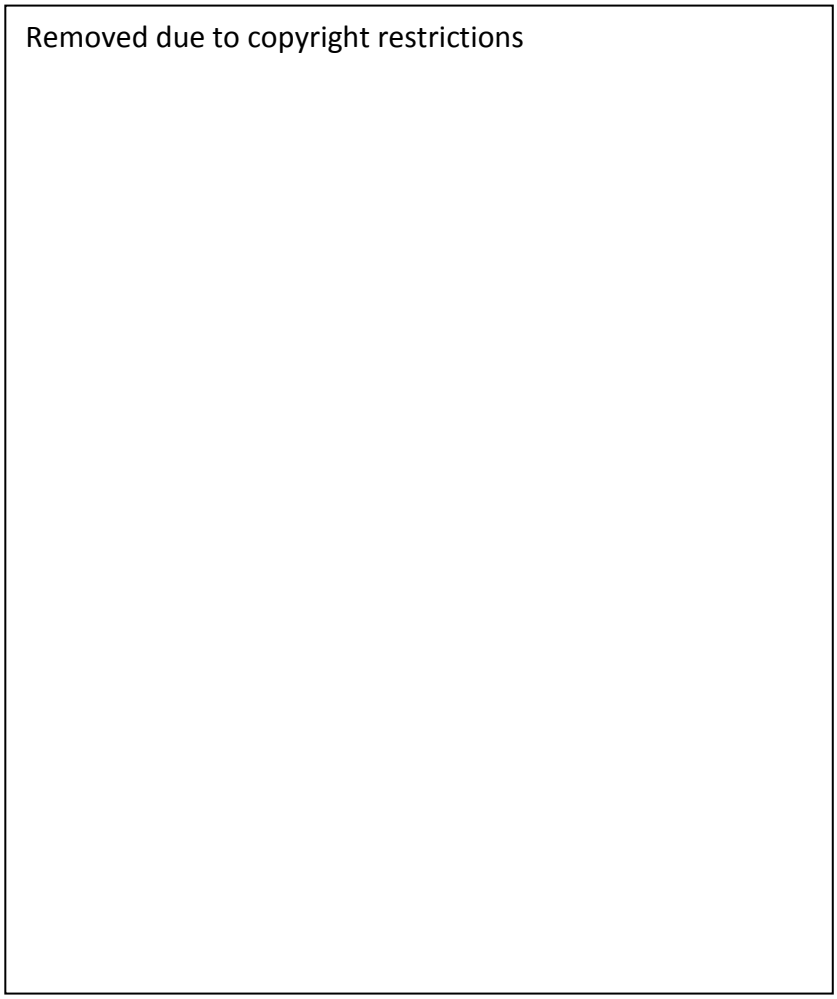


Figure 6.1 Map of the United Kingdom with the locations of the three sites highlighted (www.d-maps.com, with additions)

Table 6.2 Iron Age site summary

Site Name	Assemblage Size (All Phases)	Articulated Animal Skeletons	Associated Human Remains			Information Available	
		Y/N	Y/N	MTB complex?		Iron Age Contexts Phased? (Y/N)	Report/Raw Data Available (Y/N)
				Osseous Lesions	aDNA		
Wetwang Slack	28,292	Y	Y	Y	-	N	N
Barton Field	6,292	Y	Y	Y	Y	N	Y
Danebury	c.140,000	Y	Y	N	-	Y	Y

6.6.1 Wetwang Slack, Wetwang, East Riding of Yorkshire

In 1963, W. Clifford Watts of Bridlington re-opened a chalk pit located at Garton Slack Gatehouse (Dent 1984: 17). The recovery of human skeletons was brought to the attention of the Inspectorate of Ancient Monuments and between the years of 1965 and 1969 intermittent archaeological excavations of the quarry area were led by T.C.M Brewster. This reverted to full-time excavation on a yearly basis from 1970-1975 (Dent 1984: 17). The archaeological features and finds identified in the dry valley or 'slack' during this period of gravel extraction were located in the parish of Garton-on-the-Wolds and referred to as Garton Slack. Towards the end of this excavation period, the quarry and archaeological evidence had stretched into the neighbouring parish of Wetwang, at which point it became known as Wetwang Slack, and J.S. Dent was appointed principal supervisor until government funding was withdrawn in March 1981. Although the archaeological evidence is seemingly split between two areas, the sites of Garton and Wetwang Slack are in fact the same site, as emphasised by Dent (1984: 13): '*The finds in Garton Slack have an immediate relevance to Wetwang Slack for the two are one and the same site, distinguished only by a parish boundary*' (Figure 6.2 & 6.3). The excavations that took place under the supervision of Brewster were published in microfiche form in 1980 entitled *The Excavation of Garton and Wetwang Slacks.* The publication of the remaining excavations at Wetwang Slack by Dent is forthcoming.

Figure 6.2 Location of Excavations between the parishes of Wetwang and Garton on the Wolds (Dent 1984: Fig. 1.2)

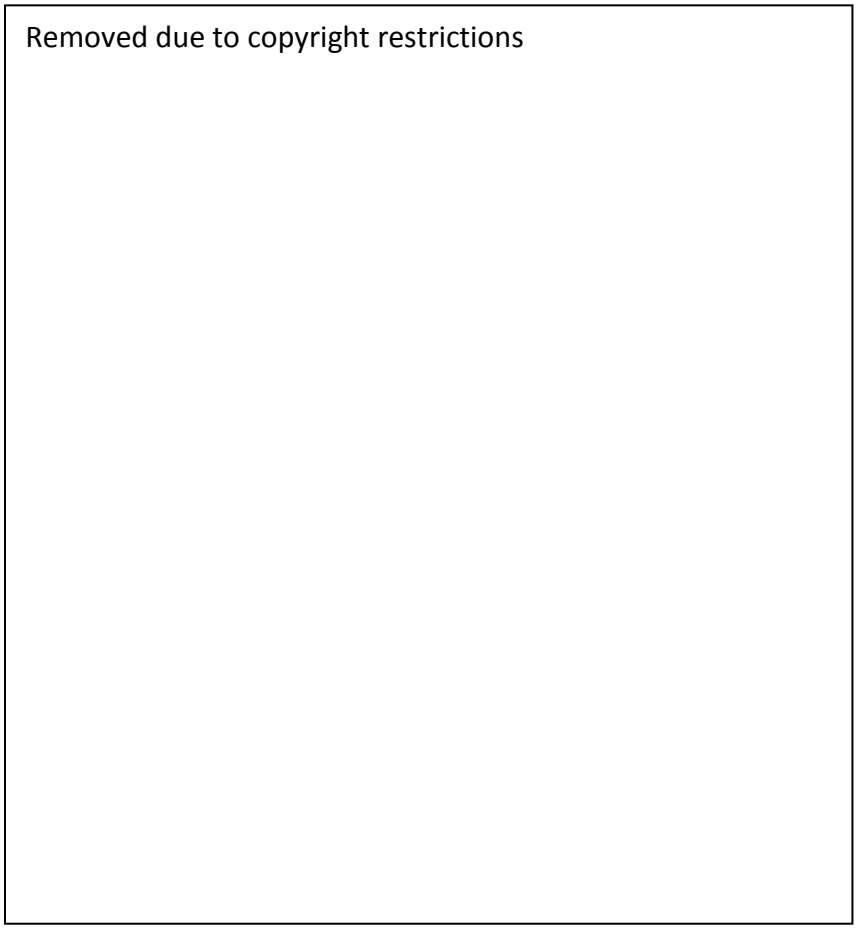


Figure 6.3 Closer view of the Excavations at Wetwang and Garton Slack (Dent 1984: Fig 1.3)

The archaeological excavations at Wetwang and Garton Slack (Grid Reference: SE 945600) revealed a multi-period landscape with activity dating from the Neolithic to the Romano-British period. The site, however, is best known for its vehicle (cart/chariot) burials dating to the Early Iron Age (see Brewster 1971; Dent 1984; Dent 1985 and Hill 2001) (Figure 6.4).

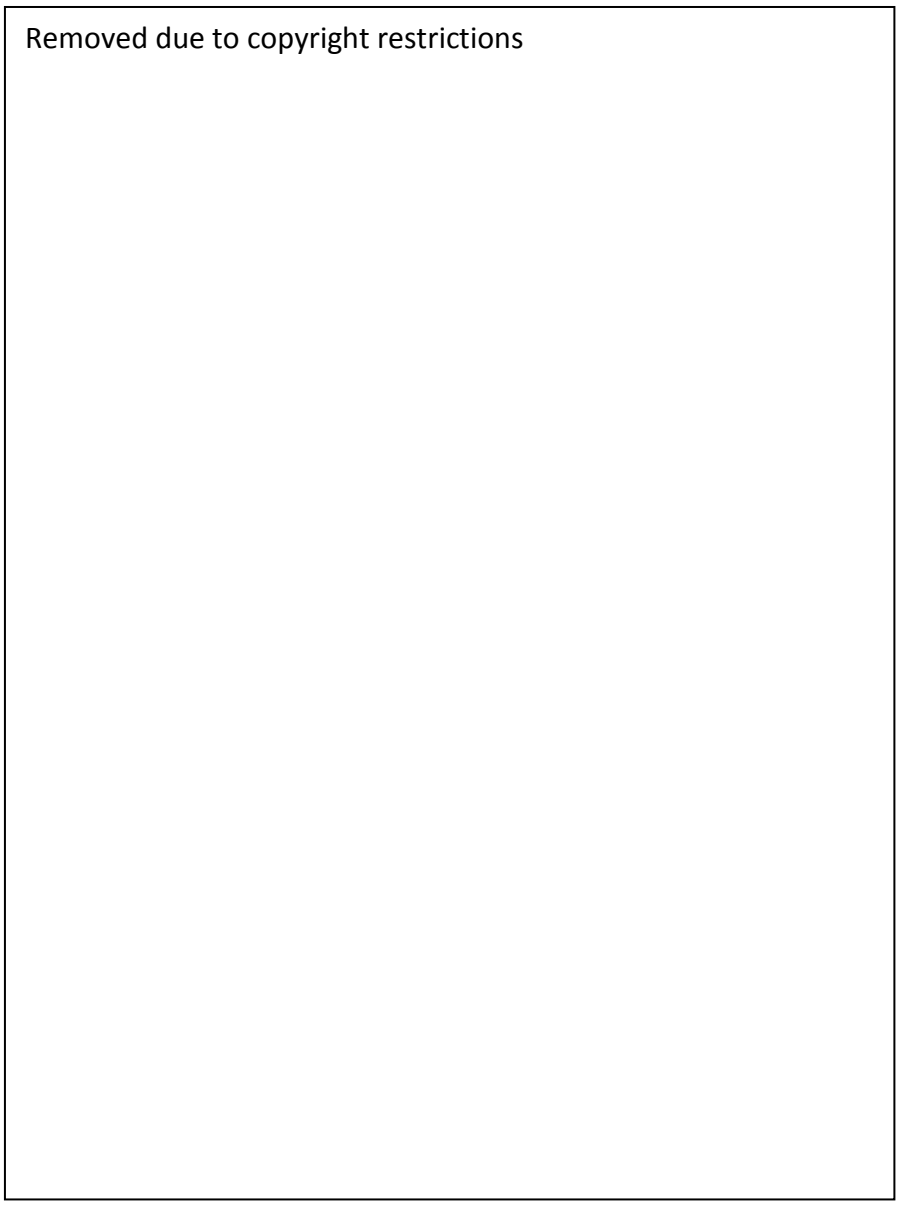


Figure 6.4 Cart/Chariot Burial No. 2 excavated at Wetwang Slack (Dent 1985: Fig 3)

These vehicle burials were identified as belonging to the 'Arras Culture', a burial tradition named after the first cemetery of its type to be excavated at the site of Arras in 1815, located near to the town of Market Weighton, East Riding of Yorkshire (Cunliffe 1975: 40). Burials of this type typically consist of a crouched or flexed skeleton, accompanied by European La Tène style grave artefacts, positioned centrally beneath a square barrow enclosed by rectilinear ditches with or without the addition of a two wheeled vehicle (Dent 1984: 120). This burial tradition is predominantly localised to the Yorkshire Wolds, although examples have also been identified in other parts of North, South and West Yorkshire (Jay & Richards 2006: 654). It has been argued that the burials conforming to the traditions of the Arras culture represent the influx of immigrants from Continental Europe, in particular, France where similar burial rites have been documented (Cunliffe 1975: 40). However, differences identified between the Yorkshire Wolds burials with those on the Continent lends themselves to the current interpretation of cultural affinity and the adoption of ideas through trade, exchange and contact (Jay & Richards 2006: 654). Indeed, this interpretation is supported by the results of an isotope study focused on the diet of the people at Wetwang Slack (see Jay & Richards 2006).

The site of Garton and Wetwang Slack is internationally important, but not solely because of the high status vehicle burials. An Iron Age inhumation cemetery and contemporaneous settlement was also excavated at Wetwang Slack. The full extent of this cemetery took five years to reveal, with evidence for the presence of 446 burials, of which, 429 skeletons were recovered and recorded by Jean Dawes (Dent

1984: 19, 20; Dawes n.d unpublished report) (Figure 6.5). A number of these skeletons were sampled for radiocarbon dating which produced a date range of c.400-50BC, calibrated at 95.4% probability (Jay *et al.* forthcoming). This date range supports the longevity of this site, but the cemetery appears to predominantly date to the Middle Iron Age (Jay *et al.* 2008:327-8). It is the largest of its kind in the United Kingdom and amongst the largest in Continental Europe (Jay *et al.* 2008: 327-8). British Iron Age inhumation burials, in any great number, are rare. Therefore, Wetwang Slack provides the exceptional opportunity to analyse an Iron Age Arras culture population. The two main differences between this cemetery and other Arras culture cemeteries elsewhere in the region are the lack of vehicle interment and, most importantly, the presence of a contemporary multi-phase Arras culture settlement, the first to be identified in Britain (Dent 1984: 14, 19, 120).

Figure 6.5 Wetwang Slack Cemetery Plan (Dent 1995: Fig 45)

The settlement at Wetwang Slack was extensive, with evidence dating from the Neolithic to the Romano-British periods (Scott n.d). The preponderance of structural evidence, however, was Iron Age and included roundhouses (presumably dwellings), post-squares (possible granaries), linear earthworks, pits and trackways (Dent 1984: 103). Dent (1984: 119) interpreted the settlement evidence along with the cemetery as representing a '*tripartite sequence of development*'. In the Early Iron Age an open settlement was located on the valley floor set out along the limits of a northerly trackway. The cemetery, in its early stages of development, was located close to a southern trackway. In the Middle Iron Age, the open settlement was gradually abandoned in favour of a more nucleated, enclosed settlement to the north of the valley floor (roughly equating to La Tène II on the continent). The cemetery, however, continued to expand during this period (see radiocarbon dates). In the later Iron Age (early La Tène III), there was an expansion of the nucleated settlement area into the wider, more marginal landscape. This was coupled with the disuse and abandonment of the cemetery, which was subsequently re-used for general animal husbandry activities (Dent 1984: 119). Dent interpreted this change in settlement typology from the Early to the later Iron Age as a reflection of population growth (Dent 1984: 119).

The skeletal remains from the cemetery at Wetwang Slack are currently on loan to the Biological Anthropology Research Centre (BARC) at the University of Bradford. Good identified twelve possible cases of TB in a palaeopathological study of the skeletal remains from Wetwang Slack (Good 2005: 30-35). Burial 220, in particular,

possessed lesions affecting the sacrum, potentially indicating infection of a bovine origin (section 3.12.5).

6.6.1.1 Wetwang Slack: The faunal assemblage

In addition to the human remains and the settlement evidence, Wetwang and Garton Slack also produced the largest Iron Age faunal assemblage identified outside of southern central Britain (Jay & Richards 2006: 654). Over 28,000 bones were recovered from Wetwang Slack ranging in date from Neolithic and Bronze Age grave inclusions to extensive contexts associated with the Iron Age and subsequent Romano-British settlement (Scott n.d). When combined with the faunal assemblage from Garton Slack (just under 16,000) (Noddle 1979) the total, in its entirety, is just over an impressive 44,000 fragments. Associated bone groups (ABGs) were also recovered from the excavations at Garton and, in particular, Wetwang Slack where 26 ABGs were identified dating to the later Iron Age/Romano-British periods. Like the inhumation cemetery, this collection of articulated animal skeletons provides the valuable and exceptional opportunity to analyse a group of articulated remains from a past herd population. It is the unpublished faunal assemblage, including ABGs from the excavations at Wetwang Slack that were selected for this research.

6.6.2 Barton Field, Tarrant Hinton, Dorset

The site of Barton Field (Grid Reference: 927118) is located on a chalk ridge overlooking the Tarrant valley in the parish of Tarrant Hinton (Figure 6.6) (Tanner &

Giles 1972). Between the years of 1968 - 1984, excavations at Barton Field revealed extensive archaeological evidence for long-term use and occupation. Five distinct periods of activity were noted: Bronze Age (Five Beaker burials and pits: 3rd/2nd Millenium BC), Iron Age settlement (round houses, pits, boundary ditch and skeletons: 6th Century BC-1st Century AD), Iron Age - Romano-British transition (pottery fragments: 1st – early 2nd Century AD), Early Romano-British settlement (buildings and bath house: 2nd and 3rd Centuries AD) and Later Romano-British (Courtyard Villa: 4th Century AD). Although Bronze Age activity was identified, the majority of evidence was associated with settlement in the Iron Age and Romano-British periods (Graham 2006: xi).

Figure 6.6 Location of the excavations at Barton Field (Graham 2006: Fig 2)

Attention was first drawn to the site in 1845, when Mr William Shipp undertook an agricultural investigation in relation to a failed turnip crop. Upon excavation of the area, he came across substantial building foundations (Tanner 1970: 189; Tanner & Giles 1971). He later stated in his personal notes: '*In a field called Barton Field in the Parish of Tarent Hinton extensive remains of a Roman temple and habitations were discovered...*' (Dorsetshire, Volume 3, 37-39 cited by Graham 2006: 1). It was not until 1968, after the field had been ploughed that the site was re-discovered by Mr A.G. Giles of Tarrant Hinton, who later directed the excavations between 1977 and 1984 (Tanner & Giles 1971). To assess the potential for further plough damage, trial excavations of the area were undertaken in 1968-69 (Tanner 1971: 152). These excavations uncovered parts of a substantial Romano-British building dating to the 3rd- 4th centuries (Tanner & Giles 1971). When compared with the discoveries of Mr Shipp over a hundred years earlier, it was clear that the area of Barton Field had been occupied for a considerable length of time. Upon approval from the Department of the Environment and in conjunction with The Priest's House Museum, Wimborne Minster, Dorset, the trial excavations were extended and two areas of the field (site 1 and site 2) were excavated by the Wimborne Archaeological Group (Figure 6.7) (Tanner & Giles 1971). The excavations continued for 16 years, initially directed by Mr. R.M. Tanner until 1976 at which point Mr. A.G. Giles was appointed until completion in 1984 (Graham 2006: 3-4).

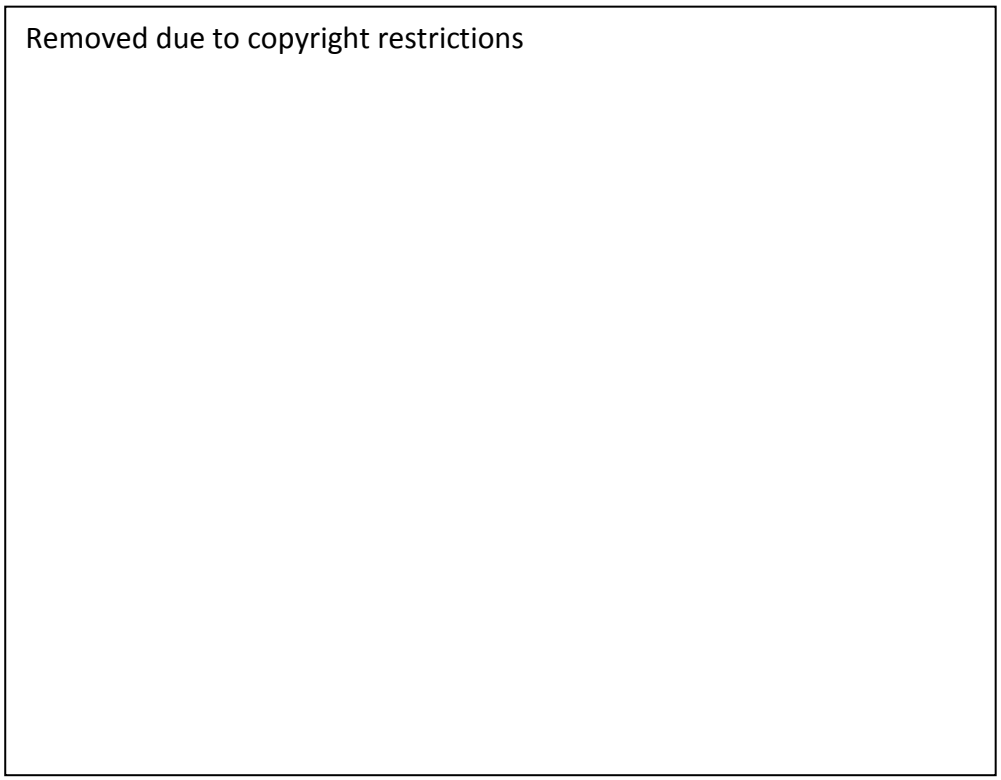


Figure 6.7 Locations of Sites 1 and 2 at Barton Field (Tanner 1975: Fig 9)

The main focus of the excavations from the start was the Romano-British structural remains. However, in 1970, it became apparent that the site had been occupied much earlier. Tanner (1971: 152) stated: '*Beneath and on the S.E. side of Building I, several Iron Age pits were discovered, one of which contained an excellent example of Iron Age B coarse ware pottery.*' Excavation of both sites 1 and 2 revealed evidence for a substantial Iron Age settlement covering an area of at least 200m. The settlement evidence comprised the remains of five roundhouses, three ditches and multiple pits along with three inhumation burials (Figure 6.8) (Graham 2006: 19).

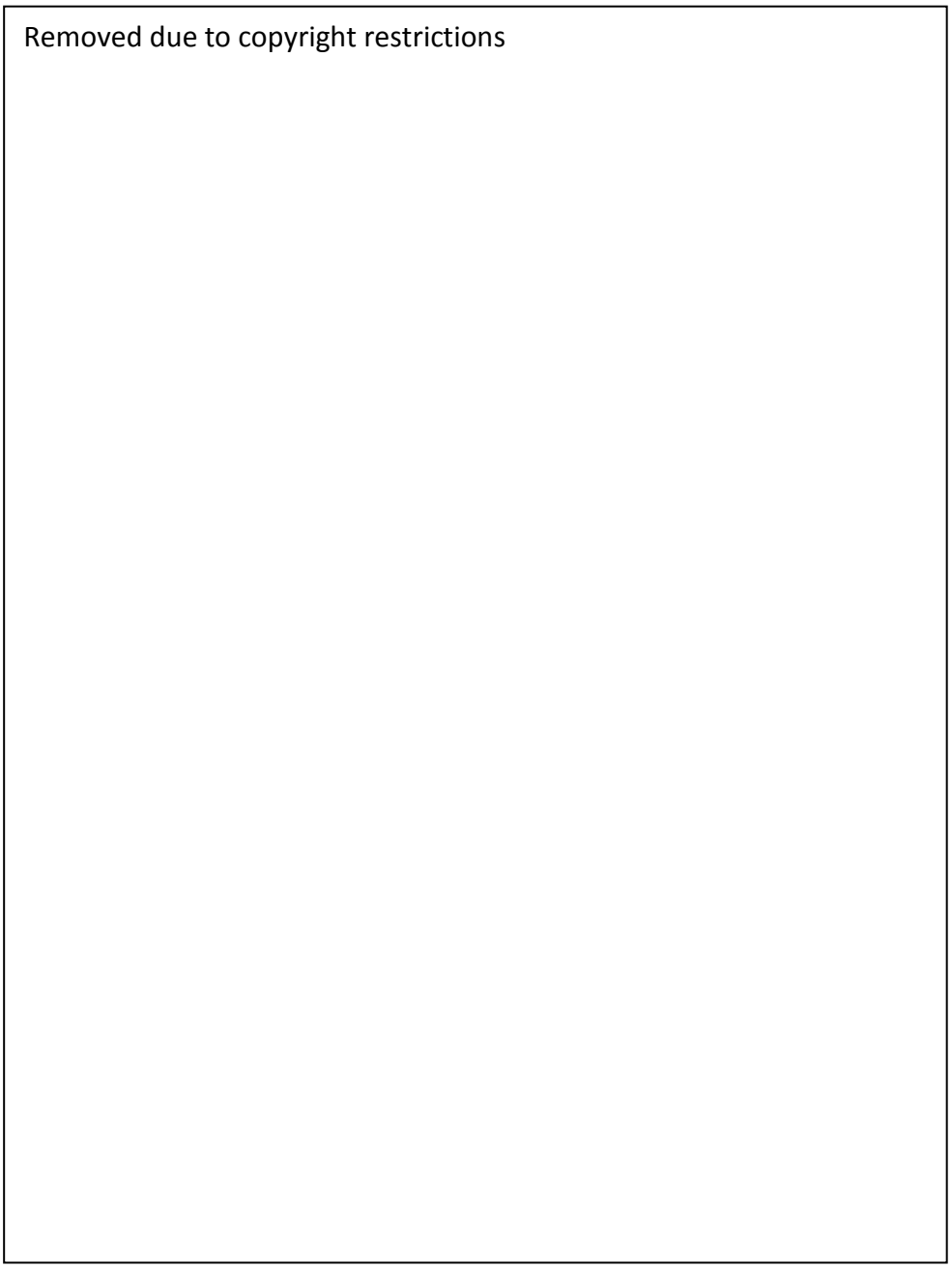


Figure 6.8 Plan of the Iron Age Settlement excavated in Sites 1 and 2 (Graham 2006: Fig 5)

One of these inhumation burials (burial 7) (Figures 6.9), is of particular interest because it represents the earliest prehistoric case of TB in the United Kingdom at present (Graham 2006: 23; Mays & Taylor 2003).

Figures 6.9 Burial 7: The Earliest Case of TB in the United Kingdom (Graham 2006: Plate 11)

This skeleton was radiocarbon dated to the Middle Iron Age (400-230 BC) (Graham 2006: 223) and possessed lytic lesions suggestive of TB. These lesions were confined to the lumbar vertebrae and when re-articulated indicated vertebral collapse and a 60 degree kyphosis (Figures 6.10) (Mays & Taylor 2003: 189). Tuberculosis was

confirmed through biomolecular testing employing nested PCR for IS6110, a multi-copy element (section 5.4.3).

Figures 6.10 Vertebral collapse leading to kyphosis (Mays & Taylor 2003: Fig 4)

Unfortunately, apart from short annual interim reports published in the *Proceedings of the Dorset Natural History and Archaeological Society*, there was no official excavation report compiled and no stratigraphic record (Graham 2006: 5). Specialists had been approached and reports were completed on the artefacts, human and animal remains, but the information remained unpublished with no established chronological relationships. In 1997, Mr. Alan Graham was approached to produce a publication of the excavations and, over the next few years a thorough

investigation of the available archive and associated notes, published reports, plans and artefacts housed at The Priest's House Museum, Wimborne Minster, Dorset, was conducted. This resulted in the publication of *Barton Field, Tarrant Hinton, Dorset* in 2006.

6.6.2.1 Barton Field: The faunal assemblage

The archaeological faunal assemblage excavated from Barton Field comprised a total of 6,292 fragments. In addition to this, there were 10 ABGs recovered during the excavations, four of which were located in the top layers of two possible Iron Age pits (Graham 2006: 31; Peck 2006: 164). The other ABGs are later in date with one goat buried with a black burnished pot dating to the Romano-British period (Graham 2006: 60-1). Even with Graham's recent publication, however, it was impossible to accurately phase the archaeological faunal remains (Peck 2006: 164). Therefore, the assemblage was considered as a whole, with no differentiation in the analysis between the Iron Age and Romano-British periods.

6.6.3 Danebury Hillfort, Nether Wallop, Hampshire

The Iron Age fort of Danebury is located in the parish of Nether Wallop, Hampshire (Grid Ref: 324377), on a hill approximately 143m above sea level (Figure 6.11) (Cunliffe 1984: 1). A ten-year programme of excavation initiated in 1969 and completed in 1978 targeted specific areas of the hillfort including most notably the defences, elaborate entrance way and the interior (Cunliffe 1984: 6). Excavation of

the hillfort, however, continued on an annual basis until 1988, after which a further seven years of excavation (1989 - 96) was undertaken on eight Iron Age sites in the vicinity of the hillfort (Cunliffe 2003: 7). This latest period of investigation was named 'the Danebury Environs Programme' and as Cunliffe (2003: 7) stated: '*Danebury has now claimed its place as the most thoroughly studied hillfort in Britain.'*

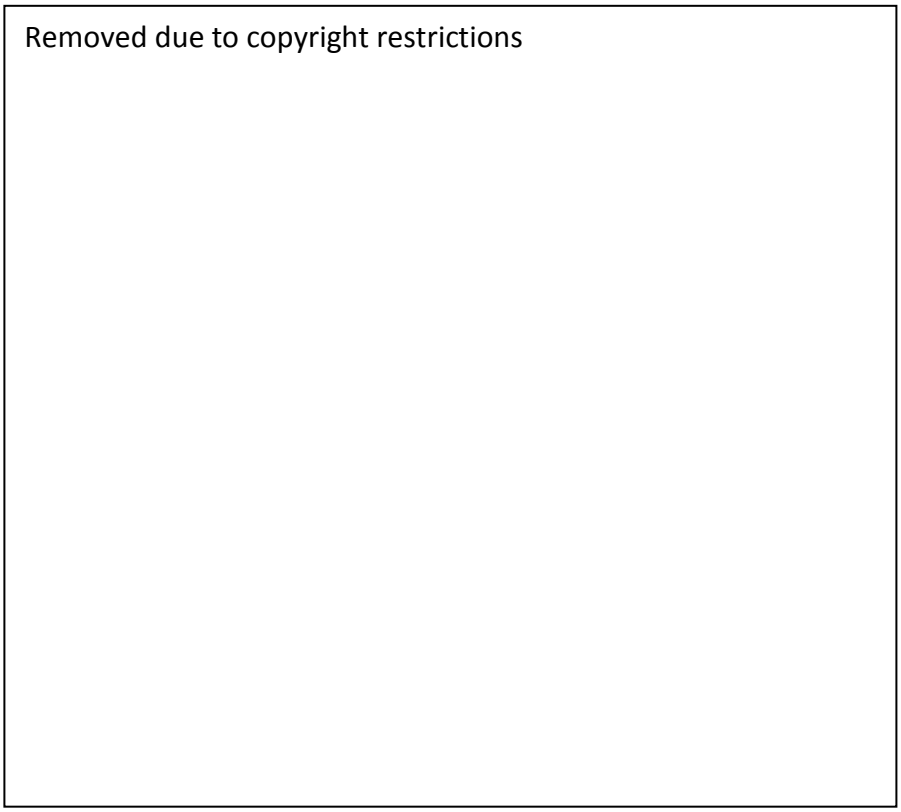


Figure 6.11 Map of the area surrounding Danebury Hillfort (Cunliffe 1984: Fig 1.2)

The location of the hillfort in the Hampshire landscape was included on a map of the county dated to 1637 and published in Camden's *Britannia* (Cunliffe 1984: 5). In the 17th Century, this landmark was referred to as 'Dunbury hill', a suspected

Roman fort, and was the subject of several sketches and paintings in the 18th century. It was investigated archaeologically for the first time by Augustus Franks in 1858 after a gamekeeper had discovered a substantial pit whilst attempting to remove rabbits from the southern portion of the site (Cunliffe 1984: 5-6). In 1910, the substantial earthworks associated with the site were surveyed, mapped and published by Dr. J.P. Williams-Freeman (Cunliffe 2003: 24). These earthworks (labelled the inner, middle and outer earthworks) comprise three distinctive circuits or enclosures (Figure 6.12).

Figure 6.12 Plan of the earthworks at Danebury Hillfort (Cunliffe 2003: Fig 5)

The development of Danebury Hillfort over time was identified through a combination of these earthwork phases (in particular the main rampart of the inner earthwork and the two entrances), the pottery typologies and the stratigraphic relationships evident in the main occupation area. The addition of radiocarbon dating enabled the formulation of an absolute chronology, of which eight periods of activity were distinguished (Table 6.3).

Table 6.3 Danebury Hillfort: Site chronology (Cunliffe 2003: Table 2)

	Period	Date
Early	1-2	470 - 310 BC
Middle	3-4	310 - 270 BC
Late	5-6	270 - 50 BC
Latest	7-8	50 BC – AD 40

The chronology of Danebury Hillfort is sub-divided into early, middle, late and latest use of the fort. The early period (470 - 310 BC) corresponds with occupation after construction of the first rampart, beginning in the Middle Iron Age. However, as Cunliffe emphasises, the fort may have been constructed much earlier than this (Cunliffe 2003: 59). The middle period was associated with the modification of the ramparts and gates and the late period again saw the modification of the ramparts and eastern entrance, but this time on a much larger scale, coupled with the blockage of the south-western entrance. The latest period corresponds to the

burning of the main eastern gate, after which use of the fort was deemed intermittent (Cunliffe 2003: 59).

The inner earthwork enclosed an area of 5.3 ha forming the main occupation area for c. 500 years (Cunliffe 1984: 1; Cunliffe 2003: 80). Evidence for settlement at the fort lay in the thousands of post-holes and pits excavated, which when viewed un-phased indicate the intensity of activity (Figure 6.13). Circular structures/roundhouses numbering c.70 were excavated representing for the most part dwelling areas. However, other uses could have included storage or animal housing, although the latter is largely dismissed because of the lack of midden deposits (Cunliffe 2003: 90). The other structural type identified commonly appears on settlement sites in Wessex: post-built structures. These structures are either square or rectangular and most often consist of 4 or 6 post-holes. The purpose of this structure type has been debated, with interpretations ranging from granaries and fodder storage to exposure platforms for the dead to watchtowers. What is clear is that the structures were elevated off the ground and the general consensus appears to support the granary interpretation (Cunliffe 2003: 94).

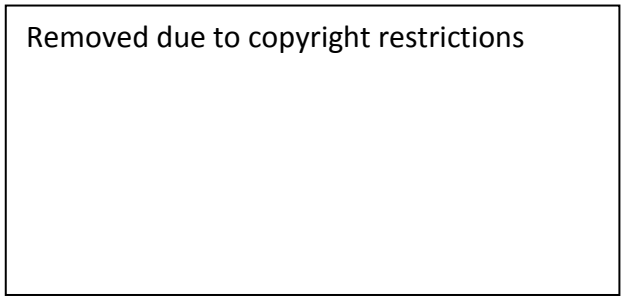


Figure 6.13 Danebury Hillfort: Settlement evidence (Cunliffe 2003: Fig 42)

It is estimated that the population of Danebury hillfort, particularly in the later periods, ranged between a possible 200-350 people (Cunliffe 2003: 94). A minimum of 70 individuals were recovered from the site, the majority from pits. Twenty-five of these were articulated inhumation burials, whereas the rest comprised incomplete and partially complete skeletal remains and disarticulated isolated skeletal elements (Walker 1984: 442). It is clear that the number of excavated human remains does not correlate with occupation and burial of the dead over a 500 year period. Therefore, it is postulated that these remains represent a specialised series of mortuary practices/rites associated with ritual belief and aimed a particular set of individuals, as opposed to the funerary traditions associated with the rest of the population (Walker 1984: 461). These remains did exhibit pathology, but TB was not among the aetiologies ventured. However, these remains were clearly not associated with the normal funerary rite and only 23% of the fort was excavated (Walker 1984: 457).

6.6.3.1 Danebury Hillfort: The faunal assemblage

The largest domestic faunal assemblage to be recovered in southern central England (c.140,000) is that associated with the first ten years of excavations at Danebury Hillfort (Grant 1984a: 496). In addition to this, a number of 'special animal deposits' were also recovered (see Grant 1984a: Table 88). The latter were divided into three main categories: articulated animal skeletons, complete skulls, or in the case of horses, complete mandibles and articulated limbs. The frequency of the articulated skeletons over all phases is presented in Table 6.4. For the purposes

of this research, the first category of 'special animal deposit' was targeted for analysis. Brothwell (1995) analysed a sample of pathological bones associated with the disarticulated domestic assemblage. This forms one of the most detailed pathological analyses of an archaeological faunal assemblage to date and was re-analysed as a part of this research.

Table 6.4 Danebury Hillfort: Special Animal Deposits (Data from Grant 1984a: Microfiche 17: E3-9)

Time Period	Articulated Skeletons
Early	19
Middle	21
Late (a)	13
Late (b)	21
TOTAL	**74**

6.7 Archaeological sites and assemblages: Viking Age/Norse

The following four sites were selected for study from the North Atlantic region: Westness, Rousay located in Orkney and Hofstaðir, Hrísheimar and Sveigakot, all located within the region of Mývatnssveit, Iceland. Westness (section 6.71) was chosen for analysis because of the suspected presence of TB in the indigenous population of the island. The excavation of Hofstaðir (section 6.7.2), along with the

nearby sites of Sveigakot (section 6.7.3) and Hrisheimer (section 6.7.4) formed part of the collaborative NABO project entitled: *Landscapes of Settlement in NE Iceland* (McGovern *et al.* 2007).

These three sites were selected for analysis because they represent high, middle and lower status farmsteads within a specific region of Iceland. Hofstaðir has a contemporary human population with suspected TB and Sveigakot and Hrísheimar are both *landnám* settlements. The following sub-sections will provide a brief synopsis of each site, providing necessary background information supporting the reasoning behind their inclusion. Information pertaining to the faunal assemblages associated with these sites is displayed in Table 6.5.

Table 6.5 Viking Age/Norse sites, Orkney and Iceland

Site Name	Assemblage Size (All Phases)	Landnám Assemblage		Associated Human Remains			Information Available	
		Y/N	Date?	Y/N	MTC Complex?		Viking/Norse Contexts Phased? (Y/N)	Report/Raw Data Available (Y/N)
					Osseous Lesions	aDNA		
Westness	20,807	N	-	Y(32)	Y*	-	N	Y
Hofstaðir	109,373	N	AD 950	Y(78)	Y	-	Y	Y
Hrísheimar	27,780**	Y	AD 871+/- 2	N	-	-	Y	Y
Sveigakot	37,732	Y	AD 871+/- 2	N	-	-	Y	Y

*The osseous lesions are associated with the Pictish indigenous individuals

** The Hrísheimar faunal assemblage is in the process of being recorded

6.7.1 Westness, Rousay, Orkney

Orkney, an archipelago located off the northern coast of Scotland comprises in the region of 40 islands (Barrett & Richards 2004: 250). Rousay is one of the largest located to the north of the mainland island on the west side of the archipelago (Figure 6.14) (Sellevold 1999: 6).

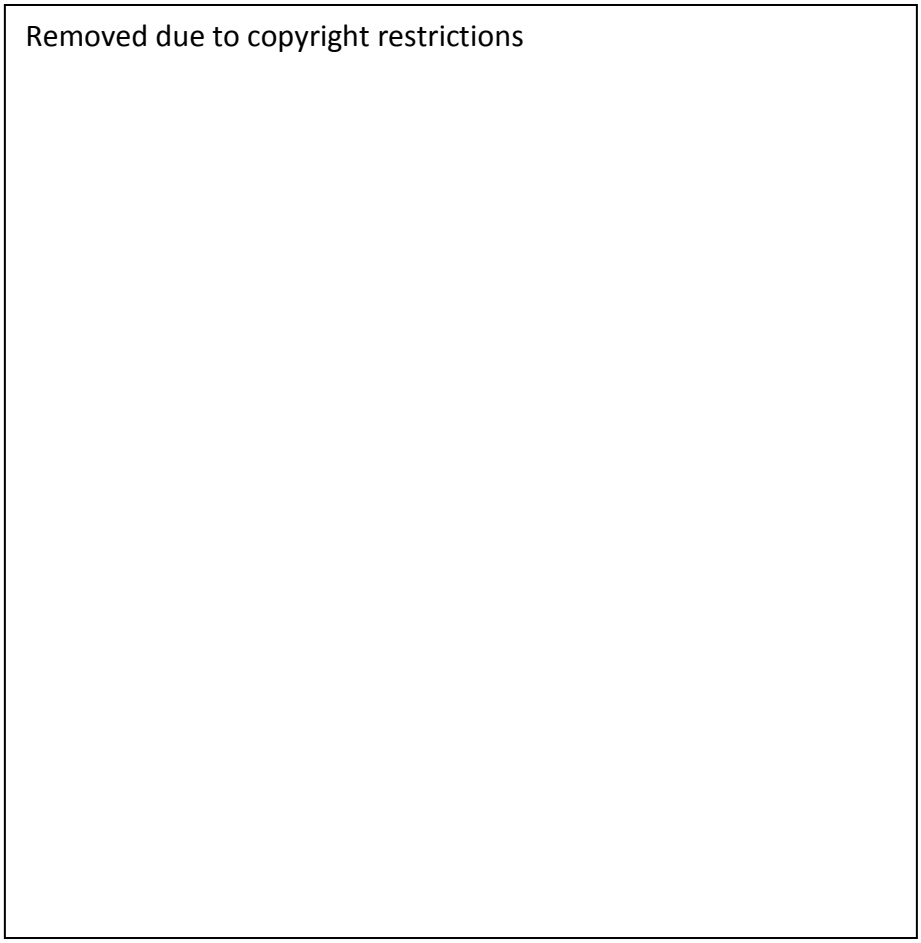


Figure 6.14 Map of the Orkney Islands with Rousay highlighted in green and the location of Westness indicated (http://www.scotlandsplaces.gov.uk/, with additions)

In 1963, a farmer burying a dead cow disturbed a grave which was later found to have contained a woman and her new-born child. The grave was richly adorned with artefacts, including a pair of oval brooches dating to the 9th century. This was the first of thirty-two graves identified at Westness on the island of Rousay, Orkney (Graham-Campbell & Batey 1998: 136). In 1968, Sigrid Kaland, a Norwegian archaeologist from the University of Bergen began excavations at the site which continued intermittently until 1984 (Sellevold 1999: 6). In addition to the cemetery, a later Norse farmstead and noust (boat-house) were also identified (Figure 6.15). The publication of the excavations is forthcoming, but Sellevold (1999) was given permission to study and publish 29 of the 32 human skeletons recovered.

Figure 6.15 Map showing the location of the Westness site and its associated structural remains (Kaland 1993: Fig 17.2)

The cemetery (Figure 6.16) was initially believed to be Viking Age based upon the first few graves excavated. However, differences in some of the later graves and subsequent radiocarbon dating indicated that the origins of the cemetery were Pictish and it had been in use between the 7th-11th centuries (Sellevold 1999: 4). The earlier graves of the native Pictish population were narrow, contained no grave goods and the bodies were in a supine position. The Viking graves, however, were more variable in form. Some were rectangular in shape with no grave goods and others were either oval-shaped or boat graves – both associated with grave goods (Kaland 1993: 313-4). It would appear from the lack of intercutting and disturbance that the later Viking immigrants respected the earlier graves (Sellevold 1999: 6).

Figure 6.16 Westness cemetery plan (after Sellevold 1999: Fig 2)

This site was chosen for analysis based upon the identification of two human skeletons with suspected TB. Both appeared to belong to the native Pictish population as opposed to the immigrant Viking's. However, these skeletons represent the only potential evidence to date for this disease in the Scottish Northern Isles. This potentially indicates the presence of a possible reservoir of infection. Grave 7 contained the remains of an elderly female with an abscess/cyst affecting the 10th thoracic vertebra spreading to the associated rib (Figure 6.17). Upon excavation, a series of bony plaques were recovered from the rib cage. These were also found in association with Grave 28 and have been interpreted as possible calcified pleura – a feature not directly indicative of TB but found in association with the disease in archaeological skeletal remains (Donoghue *et al.* 1998). Grave 28 was a young adult female, 5-6 months pregnant at death. Along with the calcified pleura fragments, this skeleton also possessed pathological change in the thoracic region of the vertebrae, with two bony lumps, one in the rib-cage and the other in the pelvic basin (Sellevold 1999: 15).

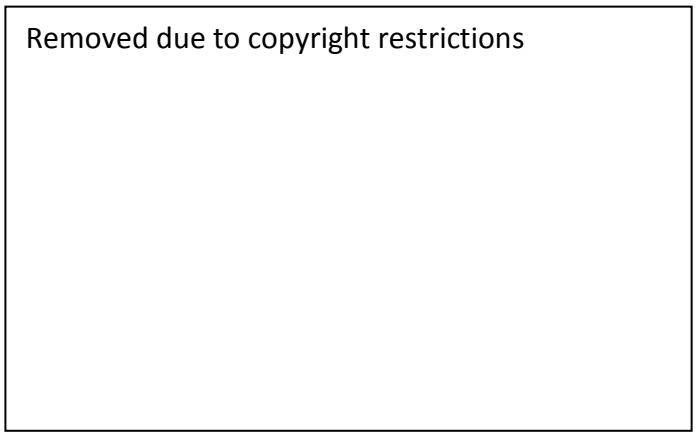


Figure 6.17 Burial 7: Vertebra and rib displaying destructive lesions possibly associated with MTB disease (Photo: Fiona Tucker)

The cemetery appears to have served a nearby farmstead for c. 500 years (Sellevold 1999: 25). Kaland excavated three longhouse structures during the excavations at Westness in addition to the noust/boat-house. House 1 was 35m in length and interpreted as the main dwelling. It consisted of two halls separated by a central room. Parallel to this were houses 2 and 3, constructed together and interpreted as animal byres. House 2 was 15m long and estimated to hold at least 18 cattle, whereas house 2 was only 5m square and assumed to have housed sheep (Kaland 1993: 308-309).

6.7.1.1 Westness: The Faunal Assemblage

The domestic faunal assemblage recovered from the excavations at Westness totalled 20,807 bone fragments. The publication of the faunal analysis is forthcoming, therefore, little is known of this assemblage outside of Bergen, Norway, where it is currently stored. The researcher was granted permission to visit the assemblage at the Museum of Zoology, University of Bergen. The majority of the bones were recovered from the excavations of the three longhouse structures and are assumed to be associated with the primary use of the buildings as opposed to the later infilling of the structures (Kaland pers. comm.).

6.7.2 Hofstaðir, Mývatnssveit, Iceland

Hofstaðir is the site of a high status Viking Age farmstead and Christian chapel located in the north-east of Iceland, close to Lake Mývatn (Figure 6.18). In the 19th century, a renewed interest in the pre-Christian Viking heritage of Iceland led to the identification of a number of sites, including Hofstaðir, as pagan temple/cult sites (Friðriksson *et al.* 2004: 191). These identifications were criticised by Finnur Jónsson who, along with Daniel Bruun, conducted an investigation, which reduced the number of possible temple sites from over a hundred to just four or five. The site of Hofstaðir, literally translated as 'temple place', was deemed a promising candidate and was subject to excavation in 1908 (Milek 2006: 249). Initial excavations by Bruun and Jónsson uncovered an extensive partitioned hall structure measuring c.45m x 10m. With a floor area of 270m^2, the excavated structure at Hofstaðir was three-four times larger than the average floor area for longhouses in 9-11th century Iceland (60m^2 – 90m^2) (Friðriksson *et al.* 2004: 191-2). The structure was subsequently interpreted as a 'banqueting hall' with an attached room for the display of pagan idols (Milek 2006: 249). Areas surrounding the structure were also investigated, in particular, a shallow depression to the south of the hall (Area G). A 'T'-shaped trench revealed stratified deposits of fire-cracked stones, charcoal and animal bones (Friðriksson *et al.* 2004: 192). The excavators interpreted this as a refuse midden used for the disposal of food waste after feasts held within the temple (Milek 2006: 249).

Hofstaðir became regarded as a type site for Viking Age temples in Iceland (Friðriksson *et al.* 2004: 191-2), but in 1965, Olsen challenged this interpretation through re-excavation of the 'T' shaped trench over Area G (Milek 2006: 249). Olsen re-interpreted the former 'refuse midden' as an outdoor cooking pit used to prepare religious feasts for the nearby farmstead, leading to the introduction of a new class of site: the 'temple farm'. Temple farms were described as elite working farmsteads, which were also regularly host to pagan ritual activity (Friðriksson *et al.* 2004: 192; McGovern *et al.* 2007: 32).

From 1991-1995, a series of archaeological assessments of Hofstaðir were conducted by Adolf Friðriksson and Orri Vésteinsson (see Friðriksson & Vésteinsson 1997). These revealed new, previously unrecorded buildings, stratified floor deposits within the hall, evidence for iron working and the discovery that Area G was in fact an abandoned pit-house, which had later been used as a midden (Simpson *et al.* 1999: 525). The archaeological deposits were located between two tephra layers, the lower of the two dating to AD 950. The site at Hofstaðir was, therefore, not established immediately after *landnám* unlike, the nearby sites at Sveigakot (section 6.7.3) and Hrisheimer (section 6.7.4). At present evidence indicates the establishment of the site in the mid 10th century with abandonment in the late 11th/early 12th centuries (Friðriksson *et al.* 2004: 192-3).

Figure 6.18 Map of northeastern Iceland showing location of Hofstaðir (after Lucas and McGovern 2007: Fig 1 with additions)

The success of these trial excavations led to a full open-area excavation of the site between 1996 and 2002. This excavation revealed the presence of several complex outbuildings (Figure 6.19), including a substantial privy (Area E2) along with a large quantity of faunal remains (section 6.7.2.1). The pit-house (Area G) was studied in great detail by Milek as a part of her doctoral research, revealing that the structure originally functioned as a subterranean space for textile production and weaving (Milek 2006: 300). The evidence, therefore, supports the interpretation that Hofstaðir was first and foremost a working farm, but it was different to the other

farmsteads in the Mývatn area with faunal evidence strongly suggestive of regular ritual activity (McGovern *et al.* 2007: 32; see also Lucas and McGovern 2007; Friðriksson *et al.* 2004). Olsens's label of 'temple-farm', hence, appears quite fitting.

Figure 6.19 Plan of the structures at Hofstaðir (McGovern *et al.* 2007: Fig 2)

Approximately 140m to the south west of the hall and the outbuildings stood a Christian chapel and cemetery, established in approximately AD 1000 (Figure 6.20) (McGovern *et al.* 2007: 32-33). The cemetery was in use from the early 11th-15th centuries (Gestsdóttir 2004: 26), the majority of the burials predating the AD 1300 tephra layer (Gestsdóttir 2006: 13-14). To date, a total of 75 skeletons have been recovered from 78 graves (Gestsdóttir 2004: 26). Although TB has not been formally

identified, the presence of visceral rib lesions on three female skeletons is indicative of respiratory infection. Therefore, TB features as one of a number of possible differential diagnoses (see Gestsdóttir 2009; Gestsdóttir pers. comm.).

Figure 6.20 Plan of chapel structural remains and associated cemetery (Gestsdóttir 2006: Fig 20)

6.7.2.1 Hofstaðir: The Faunal Assemblage

A large faunal assemblage of 109,373 fragments (Table 6.5) was recovered during the excavations at Hofstaðir (see McGovern *et al.* 2009). This research focused upon the material associated with the three main Viking Age phases (I, II and III) spanning the 10-11th centuries. The majority of the faunal material came from the midden deposits associated with areas G and E.

6.7.3 Sveigakot, Mývatnssveit, Iceland

Sveigakot is located on the southern side of Lake Mývatn to the east of the Kráká River and approximately 12km to the southeast of Hofstaðir (Figure 6.18) (Tinsley 2004: 213). The site is not detailed in any historical sources and is not listed on Magnússon's and Vídalín's 1712 land register. It does, however, appear on records for the area in the later 20th Century, the ruins presumably exposed through erosion in the 18th and 19th centuries (Vésteinsson 2001: 4, 5). In 1998, the area of the site was surveyed by the Institute of Archaeology in Iceland (Fornleifastofnun Íslands: FSÍ). A scatter of weathered animal bones were collected and the remains of three structures (Structures 1, 2 and 3) were identified (Vésteinsson 2001: 7, 8). The site was then subject to excavation from 1999-2006 by the FSÍ and the North Atlantic Biocultural Association (NABO) (McGovern *et al.* 2007: 33). In comparison to the later date of Hofstaðir, Sveigakot was established some 80 years earlier, with substantial sheet midden deposits (Area M) identified directly on top of the *landnám* tephra dating to AD 871 +/-2 (McGovern 2003: 2). Although the location of the site in modern times (on the edge of the large central eroded desert) is somewhat bleak and barren with no vegetation, it was once a densely forested area with evidence for tree stumps beneath the *landnám* tephra (McGovern *et al.* 2004: 2).

The excavation of Sveigakot produced evidence for a complex series of multi-phase structures and deposits (Figure 6.21). The earliest structural remains to be identified to date in northeast Iceland were excavated at Sveigakot (Vésteinsson 2004: 30).

These included a sunken feature building (P1), predating the Veiðivötn tephra (AD 940) (Gísladóttir 2008: 18). Other than the earliest phase of sheet midden material (Area M), the rest of the archaeological remains identified post-dates AD 940. To the south of Area M, a sunken feature building (Area T) was excavated. This subterranean feature, measuring 2m x 2m, contained the densest collection of faunal remains identified so far in Iceland (Tinsley 2004: 213). A series of domestic and farm buildings (Area S) were identified north of Area M and probably account for the later material deposited in this area (McGovern *et al.* 2004: 2). The agricultural buildings consisted of a turf walled/timber structure interpreted as an animal byre, later used as a smithy (S7) along with a paved pathway (SP). Numerous stake holes within the byre structure indicate animals were being tethered as opposed to stalled (Vésteinsson 2008: 14).

The domestic buildings consisted of the remains of a hall (*skáli*) with evidence for two main structural phases (Structures 1 & 4), with later additions (Structures 2-5). The later of the two (Structure 1) relates to a narrow building measuring 10 x 3.5m – small by comparison to other Icelandic long-houses (Milek 2002: 9). This structure was in use until the mid-late 12th century (Milek 2002: 12). The earlier structural phase (Structure 4) dating to the late 10th – 11th century (Milek 2002: 21) relates to a slightly larger building measuring 12-15m x 5m (Milek 2003: 23). The occupation of this area was not continuous. Structure 4 was abandoned in the early 11th century and the area was then used sporadically with evidence for temporary hearths. It is postulated that the structure was used for short-term shelter – a

possible shieling (Milek 2002: 21). The area was then re-occupied in the mid 11th century and the abandoned building altered to form structure 1 with the addition of a pantry/kitchen (Structure 5) and a paved byre (Structure 3) (Milek 2003: 23). The size of the *skáli* was reduced from approximately 60^2m to around 35^2m (McGovern *et al.* 2004: 3).

Figure 6.21 Plan of the excavated areas and structures at Sveigakot (Tinsley 2004: Fig 1)

The reduction in size of the later *skáli* at Sveigakot has been interpreted as a symbol of diminishing status over time. When the area was originally settled just after *landnám*, a low status site was established. This site developed and grew in status becoming more affluent by the mid 10th century. However, from the early 11th century onwards, the site displays evidence for a declining status, illustrated by its brief abandonment and subsequent re-building of a smaller *skáli* in the 11th century and its final abandonment in the 12th century (McGovern *et al.* 2004: 2).

6.7.3.1 Sveigakot: The Faunal Assemblage

A faunal assemblage of just over 37,000 fragments (Table 6.5) was recovered from the excavations at Sveigakot. This assemblage is an important resource because it provides an assemblage comparable to that of contemporary Hrísheimar and the later Hofstaðir. The majority of the material was recovered from the sheet midden (Area M) and the sunken feature building (Area T). The majority of the faunal material is securely dated to phases I-III spanning the 9th – 12th centuries. This assemblage has been recorded in its entirety, and a full analytical report is forthcoming.

6.7.4 Hrísheimar, Mývatnssveit, Iceland

Hrísheimar is located to the southeast of Lake Mývatn and to the west of the Kráká River opposite the site of Sveigakot (Figure 6.18). As the site (along with Sveigakot) is positioned to the south of Lake Mývatn, it borders the interior erosion desert and as such has been subject to heavy wind erosion (McGovern *et al.* 2004: 2). A large portion of the original soils and archaeological deposits/layers have unfortunately been obliterated, but five seasons of excavation have revealed an unanticipated wealth of archaeological remains (Edvardsson & McGovern 2007: 5).

Hrísheimar was also settled earlier than Hofstaðir with anthropogenic deposits identified directly on top of the *landnám* tephra dated to AD 871+/-2. The combination of this and a second tephra horizon (the Veiðivötn tephra – V950) dated to the mid 10th century led to the definition of two main phases of activity:

Phase 1 AD 875-950 and Phase 2 AD 950-1050 (Edvardsson & McGovern 2007: 4). The date of the final occupation of Hrísheimar was targeted through radiocarbon dating. These dates indicated that the site was occupied for a relatively short period of time - c. 125-150 years. Hrísheimar, therefore, appears to have been abandoned prior to the fall of the H1104 tephra (Edvardsson & McGovern 2007: 4).

The site was initially surveyed on a small scale in 2000 to assess the potential for further research as a part of the Landscapes of Settlement Project. In 2001, the total site area was surveyed accompanied by the excavation of test pits. Several features were recorded, including: a farm mound, two slag pits, a field boundary and a number of structures (Edvardsson 2003:3). A test pit measuring 2x2m was placed over an area to the southeast of the farm mound where a number of animal bones were observed eroding to the surface (McGovern & Woollet 2003: 2). Midden deposits to a depth of 60cm were identified, with the largest context (003) containing over 4000 well-preserved animal bones (see McGovern & Perdikaris 2002). These midden layers were found to be filling an earlier sunken feature building (Area H) (McGovern & Tinsley 2001: 1). Later excavation of this structure led to its interpretation as a workshop for the possible production of textiles (Edvardsson 2005: 17).

Excavation at Hrísheimar continued until 2006 with two main areas of concentration: Areas A, B and C located 60m west of the farm mound and Areas E,

H, L and Q on the eastern side of the farm mound (Figure 6.22) (Edvardsson & McGovern 2007:5).

Figure 6.22 Map of the excavation areas at Hrísheimar (Edvardsson 2003: Map 2, with additions)

When the site was initially surveyed in 2000, two slag pits were located indicating industrial activity (Edvardsson 2003: 24). From 2003 onwards, the excavation of areas A, B and C produced further evidence for industrial activity but on a much larger and more intensive scale. A total of 21 iron smelting furnaces (19 small and 2 large), along with a structure interpreted as a smithy, were excavated. This complex of industrial structures is the first of its kind to be identified in Icelandic archaeology (Edvardsson & McGovern 2007: 5). One of the reasons ventured for the abandonment of this site is the exhaustion of both local woodland and bog iron resources leading to eventual extensive soil erosion (Edvardsson 2003: 25).

Areas E, H, L and Q produced evidence for the accumulation of extensive midden material both over expansive areas (sheet midden) as well as forming the fill of earlier sunken feature buildings. In area E, three features were identified: two pit houses (C and D) and structure S. Structure C was found to contain a hearth and a line of *in situ* loom weights on the upper floor layer. Structure D was a sunken feature building on two levels and potentially represents the oldest latrine in Iceland (Edvardsson & McGovern 2007: 6, 11). By comparison, structure S is the earliest in date but is not a sunken feature building. It is better described as a depression in association with a number of post holes and possibly represents the remnants of a tent structure/temporary campsite related to the early development of the farm. The finds from the middens, pit houses and other structures indicate that Hrísheimar was farmed in addition to being as used as a base for industrial activity. No long-house or *skáli* has been excavated to date, but it is strongly suspected that the remains of this lie beneath the farm mound (mound R) (Edvardsson & McGovern 2007: 17).

6.7.4.1 Hrísheimar: The Faunal Assemblage

The faunal assemblage from Hrísheimar is extensive and is still in the process of being recorded. The faunal assemblage is still in the process of being recorded (Table 6.5) with preliminary interim reports produced after each excavation season (see McGovern & Tinsley 2001; McGovern & Perdikaris 2002; McGovern & Woolett 2003; McGovern *et al.* 2006). The bones were largely recovered from the midden

deposits excavated in Areas E, H, L and Q (see Figure 5.29) and relate to phases I-III dating from the 9th to the early 11th centuries.

7. METHODS (I): RECORDING THE ASSEMBLAGES

7.1 Introduction

This chapter details the way in which the assemblages were recorded. The chapter is divided into three main parts: sections 7.2 and 7.3 present and discuss both the zooarchaeological and palaeopathological approach to the recording of the faunal assemblages selected for analysis. Section 7.4 details the way in which the assemblages were recorded, incorporating the information presented in the preceding sections.

7.2 Zooarchaeological approach

A generic method was devised for the purposes of recording those zooarchaeological assemblages and ABGs chosen for study. There is no universal standard available in zooarchaeology comparable to that of *Standards for Data Collection for Human Skeletal Remains* (Buikstra & Uberlaker 1994). However, the specific recording criteria discussed below (section 7.2.1) are well-established in zooarchaeological practice (see Reitz & Wing 1999; O'Connor 2000 for reviews). Recording codes and abbreviations followed those employed by the North Atlantic Biocultural Association (NABO), with some additions. These are outlined in the NABONE zooarchaeological database *Recording System Codes* (NABO, Zooarchaeology Working Group, 9th Edition, 2008).

7.2.1 Zooarchaeological recording criteria

The selection of zooarchaeological criteria focused upon providing quantifiable data that would enable the analysis of age-at-death, skeletal element representation and, where possible, sex for the pathological bones recorded. Less emphasis was placed upon the detailed recording of taphonomic factors such as bone modification (butchery, burning, gnawing and fragmentation) as these were not central to the research aim. Age-at-death and skeletal element representation form the foundation for interpretation in zooarchaeological analyses and in this instance are key to the further understanding of bovine tuberculosis and its pathogenesis (particularly skeletally) in the three stock domesticates: cattle, sheep/goat and pig. Sex to a lesser degree is also important especially in the consideration of palaeoepidemiology. However, the difficulties associated with accurately assigning sex to faunal remains, even those that are articulated, have relegated it to minor role in this research.

7.2.1.1 Species Identification and Skeletal Element Representation

The bones were identified as far as practicable to genus, species and skeletal element aided by the faunal reference collection located at the University of Bradford. For those assemblages recorded away from the University of Bradford, the *Atlas of Animal Bones* (Schmidt 1972) was consulted. Boessneck's (1969) work aided in the differentiation of sheep and goat, particularly post-cranial elements. As this differentiation is notoriously difficult, the majority of identifications were recorded as ovicaprids (OVCA). Skeletal elements were identified and recorded

using anatomical zones following those published by Serjeantson (1996). Zoning for the mandible (which was not outlined by Serjeantson) were adapted from those used by Dobney and Reilly (1988) (Browning pers. comm.). Metrical data was collected from both pathological, disarticulated elements and articulated ABGs (where completeness allowed) following von den Dreisch (1976). Specific measurements were chosen to aid in a) the estimation of sex, where possible (H1 measurement as outlined by Greenfield 2005) and b) the calculation of body size and withers height.

7.2.1.2 Age-at-Death and Sex

Epiphyseal fusion, tooth eruption and tooth wear were the core criteria used to calculate age-at-death. Where preservation allowed, epiphyseal fusion was recorded and compared with figures published by Silver (1969) and Reitz and Wing (1999: Table 3.5). Age-at-death based solely upon epiphyseal fusion can only provide a minimum age range related to the last fusing bone, making it difficult to differentiate between fully-fused young adult animals and much older animals (Hambleton 1999: 61; Greenfield & Arnold 2008: 837). Another limiting factor includes preservational bias; unfused bones from immature and very young animals are more prone to fragmentation and disintegration compared to the more robust skeletal elements associated with mature animals (Greenfield & Arnold 2008: 837). The issue of differential preservation not only creates the potential for a noticeable bias in assemblage mortality profiles, but it also impedes our understanding of disease manifestation and representation in the younger animals of the herd.

Therefore, epiphyseal fusion is a valuable tool when determining the age of suitably preserved bones from younger animals, but for older, fully-fused animals, tooth eruption combined with tooth wear provides a more reliable indication of age. Mandibles are generally quite robust skeletal elements adding weight to their use for ageing. Two main methods of analysis exist for recording tooth eruption and tooth wear in the three main domesticates: Grant (1982) and Payne (1973), along with Halstead (1985), who produced wear stages for cattle teeth based upon Payne's method. Different researchers tend to favour one or the other of the two main methods or, alternatively, use their own method (Hambleton 1999: 64). Up until recently, comparability of tooth eruption/wear data between assemblages that have been recorded using either of the two methods or indeed a researcher's own method has proved problematic. This again highlights the need for standardised guidelines as emphasised in Chapter 2. However, extensive research within this field has provided a means of comparing the data produced from using either method and has also enabled the different stages to be discussed in terms of absolute age categories (see Hambleton 1999; Greenfield & Arnold 2008). The use of absolute age classes enables the better interpretation of mortality profiles and, as a result, husbandry techniques. For the purposes of this research, tooth eruption/wear was recorded using Grant's (1982) tooth wear stages for cattle, sheep/goat and pig. Grant's work was chosen over Payne's (1973) because the latter is only applicable to sheep/goat. Even though Halstead (1985) adapted Payne's method for cattle teeth, Grant's was preferred in order to ensure the recording was both quick and consistent for cattle, sheep/goat and pig. Only *in-situ*

mandibular teeth (dp4, P4, M1-3) were recorded on those mandibles found to be pathological as well as on all the ABGs analysed. It must be highlighted that pathological alteration of the teeth or mandible of an animal may lead to abnormal attrition and an inaccurate tooth wear calculation. Therefore, any obvious pathological change that may have affected attrition or clearly did affect attrition, such as chronic periodontal disease leading to tooth loss or arthropathy of the tempro-mandibular joint, were noted in an attempt to avoid ageing bias. Reference tables devised by Hambleton (1999) (Appendix 6.1: 64-65) that list age classes for both the Grant and Payne wear stages were employed. These age classes were then converted into descriptive age categories after O'Connor (1988). In addition to epiphyseal fusion and tooth eruption/wear, cattle horn cores associated with the ABGs were also assigned age-at-death estimations based upon the criteria outlined in Armitage (1982).

Assigning sex to disarticulated skeletal elements is problematic, but not impossible if the right elements are available and in a good state of preservation. Determination of sex is achieved through a combination of metrical and morphological analyses. A disadvantage with some metrical analyses is that a large sample of measurable fully-fused elements is needed in order to highlight data clusters that may then be interpreted as male, female or indeterminate/possible castrate. Another complication is the size differences of different breeds. This is most challenging when analysing urban town assemblages as the population comprises animals supplied from different herds and, in some instances, from

different parts of the country; a factor highlighted by O'Connor at York (2003: 194). For the purposes of this research, estimation of sex was only attempted (where completeness allowed) on the articulated ABGs studied. Table 7.1 outlines the main methods used.

Table 7.1 Morphological and metrical criteria for sex estimation

	Morphological Criteria and References	Metrical Criteria
Cattle	Pelvis morphology: Grigson (1982) Horn core size and shape: Armitage & Clutton-Brock (1976)	H1 measurement Greenfield (2005)
Sheep/Goat	Pelvis morphology: Boessneck (1969)	H1 measurement Greenfield (2005)
Pig	Size and shape of canines: Payne & Bull (1982); Hillson (2005)	-
Horse	Presence/absence/size of canines (Hillson 2005)	-
Dog	Presence of baculum	-

7.2.1.3 Quantification

Due to the size of the assemblages selected for analysis and time constraints, it was not deemed feasible or necessary to re-record them in their entirety. With the exception of Wetwang Slack, the other assemblages selected for study had been the subject of full analysis resulting in either a final published report (Barton Field, Tarrant Hinton and Danebury Hillfort), a series of unpublished interim reports (Hofstaðir, Hrísheimar and Sveigakot) or, as was the case with Westness, a report that was pending but the raw data was made available. In the

majority of these cases, basic quantification data in the form of total number of fragments (TNF), number of identified specimens (NISP) and minimum numbers of individuals (MNI) was obtained. The assemblage from Wetwang Slack was fully recorded in the 1980s, but only a brief summary report exists that contains no raw data or detailed quantification (Scott n.d.). In order to provide the basic data needed for a TNF and a NISP count for the assemblage from Wetwang Slack, a basic assessment of the contexts was conducted. Unfortunately, it was not possible to calculate MNI for this assemblage as there was not the time to record each fragment of bone individually. Only those bones found during the course of the assessment to be pathological were fully analysed.

There has been much debate concerning the validity of quantification methods such as NISP and MNI (see Reitz & Wing 1999: 191-221; O'Connor 2000: 54-67); however, in order to calculate the frequency of certain bone abnormalities per species, a NISP value at the very least is required. MNI as the name suggests can only provide a minimum number of potential individuals within a death assemblage. However, if a particular type of pathological alteration is observed on an element that can be sided (for example, enthesophytes on the distal humerus and proximal radius, colloquially referred to by some as 'penning elbow' in sheep), then at the very least a crude prevalence for this type of pathology within the assemblage could be calculated. Therefore, for the purposes of this research, NISP and MNI form the main quantification methods employed.

7.3 Palaeopathological approach

There are currently no widely adopted standardised methodological guidelines for the recording of palaeopathology in zooarchaeology. Therefore, the approach taken to recording pathological specimens was based upon suggestions and guidance provided in numerous texts, including most notably: Chaplin (1971), Baker & Brothwell (1980), O'Connor (2000, 2003), Ortner and Putschar (1981), Ortner (2003) and Vann & Thomas (2006).

7.3.1 Palaeopathological Recording Criteria

The primary aim of this research was to produce criteria for the identification of bovine tuberculosis in archaeological faunal remains. Therefore, the use of the term 'criteria' in this section refers to the manner in which bone abnormality was descriptively recorded in order to identify such criteria as opposed to the use of a specific method or scoring system. The emphasis was, therefore, placed upon the detailed description of pathological specimens using established nomenclature alongside the compilation of a detailed photographic archive. Ortner & Putschar (1981) identified three factors critical to the descriptive recording of bone abnormalities: 1) unambiguous terminology, 2) precise identification of the location and distribution of abnormal bone and, 3) a descriptive summary of the morphology of the abnormal bone (Ortner & Putschar 1981: 36). These key factors form the basic doctrine followed in the

development of a framework of practice for the descriptive recording employed in this research.

7.3.1.1 Framework of practice: terminology

The use of unambiguous terminology (both pathological and anatomical) to aid in the description of bone abnormality, its location, distribution and extent is of paramount importance to the further development of palaeopathology in zooarchaeology. The frequency of different categories of abnormality (section 7.3.1.2) needs to be compared and contrasted, both within and between assemblages to facilitate a better understanding of past animal health on a more expansive scale (O'Connor 2000: 108). Description using clear, well-established terms would make such data comparisons easier and more productive. An established nomenclature is utilised in human osteoarchaeology (see Ortner & Putschar 1981; Buikstra & Uberlaker 2004; Ortner 2003). Therefore, the glossaries in these texts, along with *Black's Veterinary Dictionary* (Boden 2005) and the glossary published on the ICAZ Animal Palaeopathology Working Group (APWG) website (http://www.apwg.supanet.com/glossary.htm) were used to ensure that any abnormalities identified in the faunal assemblages analysed were clearly described and identified.

In addition to descriptive text, the necessity of also having a visual accompaniment was emphasised by O'Connor (2000: 109). The use of

photography over the production of line sketches was preferred in this instance to speed up the recording process and to ensure maximum detail and minimum misinterpretation. The latter provided a means for further exploration of potential differential diagnoses post-recording, along with forming a valuable resource for future researchers to access. Photographs were taken of pathological specimens using a Fuji finepix digital camera. A number of pathological specimens were also radiographed (section 8.5) and sampled for ancient DNA (aDNA) analysis (section 8.6).

7.3.1.2 Framework of practice: Categories of abnormality

In order to identify the aetiology of a specific abnormality and gain a better understanding of the disease process responsible, descriptive recording needs to adequately communicate the morphology of the abnormality in question, and more specifically the lesion type and its status: for example, does the abnormal bone display a proliferative (osteoblastic) or a lytic (osteoclastic) lesion and at what stage of remodelling is it? Is it active, healed or healing? All of this information when pieced together enables the better understanding of the disease process that resulted in the abnormality.

Ortner outlines five descriptive categories for the classification of abnormalities affecting bone (Ortner 2003: 45). These include: abnormal bone formation, abnormal bone destruction, abnormal bone density, abnormal bone size and

abnormal bone shape (Ortner 2003: 45). These basic categories provide a solid platform from which to begin the process of classifying an abnormality. For the purposes of this research, these were expanded upon to include more detail and then incorporated into a pathological recording form specifically devised for the disarticulated assemblages. For the articulated remains, a more basic recording approach was employed, but the same basic categories of abnormality were referred to in order to assess each pathological skeletal element individually prior to the assessment of lesion distribution (section 8.3) and differential diagnosis (section 8.4).

7.4 Recording the data

Vann recently devised a generic methodology for the recording of pathological faunal remains for her doctorate (see Vann & Thomas 2006; Vann 2008). There are several reasons why this recording database was not used to record the faunal assemblages selected for this research. Firstly, the database was still in its developmental stages when the present research was underway; secondly, the recording system designed was presented as a stand-alone database, solely focused upon the recording of pathology and not the other zooarchaeological criteria outlined in section 7.2.1; lastly, the purpose of this research was not to produce a detailed pathological report of several different assemblages. There are certain pathologies, for example trauma, congenital, oral and some degenerative arthropathies (age and activity-related), which although

interesting, did not necessitate the detailed recording and scoring that Vann's database includes. The data was, therefore, recorded using two formats: *Excel 2007* and *Access 2007*.

7.4.1 The recording of associated bone groups (ABGs)

A simple data entry spreadsheet was created using *Excel*. Each ABG, whether it was a fully articulated skeleton or partially articulated, was identified and recorded. Where preservation of elements allowed, a full inventory was taken and age-at-death, sex and stature recorded. Any pathological bones identified were described in full and photographed. The location of the specific abnormality was clearly described and further pinpointed using Serjeantson's zoning system (Serjeantson 1996). Those ABGs found to possess no macroscopic pathological lesions or abnormalities were still subject to full recording (where possible), so that a profile of the herd population could be created.

7.4.1.1 The recording of disarticulated assemblages: Basic assessment and full analysis

The disarticulated assemblages from all seven sites were recorded using *Access. Access* was favoured over *Excel* for the disarticulated assemblages because large numbers of bones were being analysed. A feature of the *Access* software is the ability to create detailed, yet user-friendly recording forms that can incorporate drop-down menus and tick boxes for quick data input.

The faunal assemblage from Wetwang Slack and Westness required a basic assessment in order to provide a TNF and NISP count. A simple recording form was created using *Access* (Figure 7.1). Any bones found to be pathological during the course of the assessment were then subject to full analysis using the core data and pathology recording form (Figure 7.2).

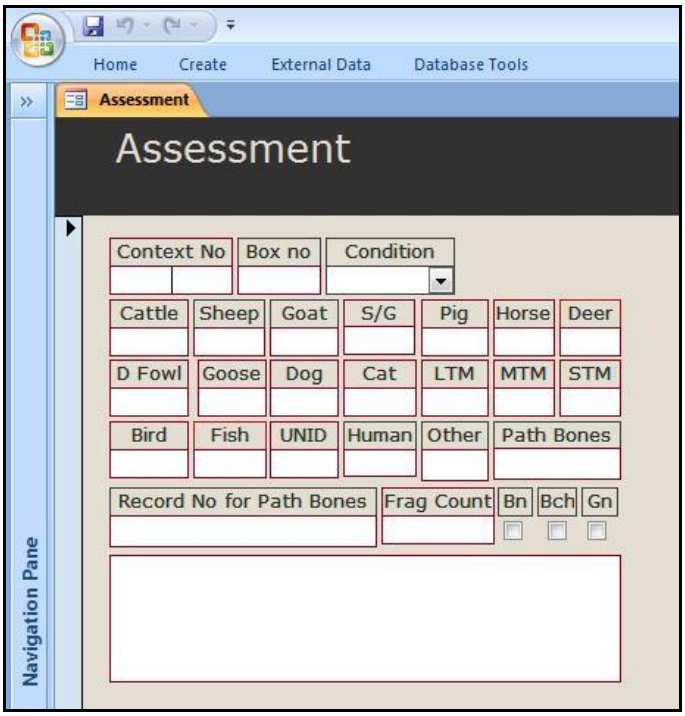
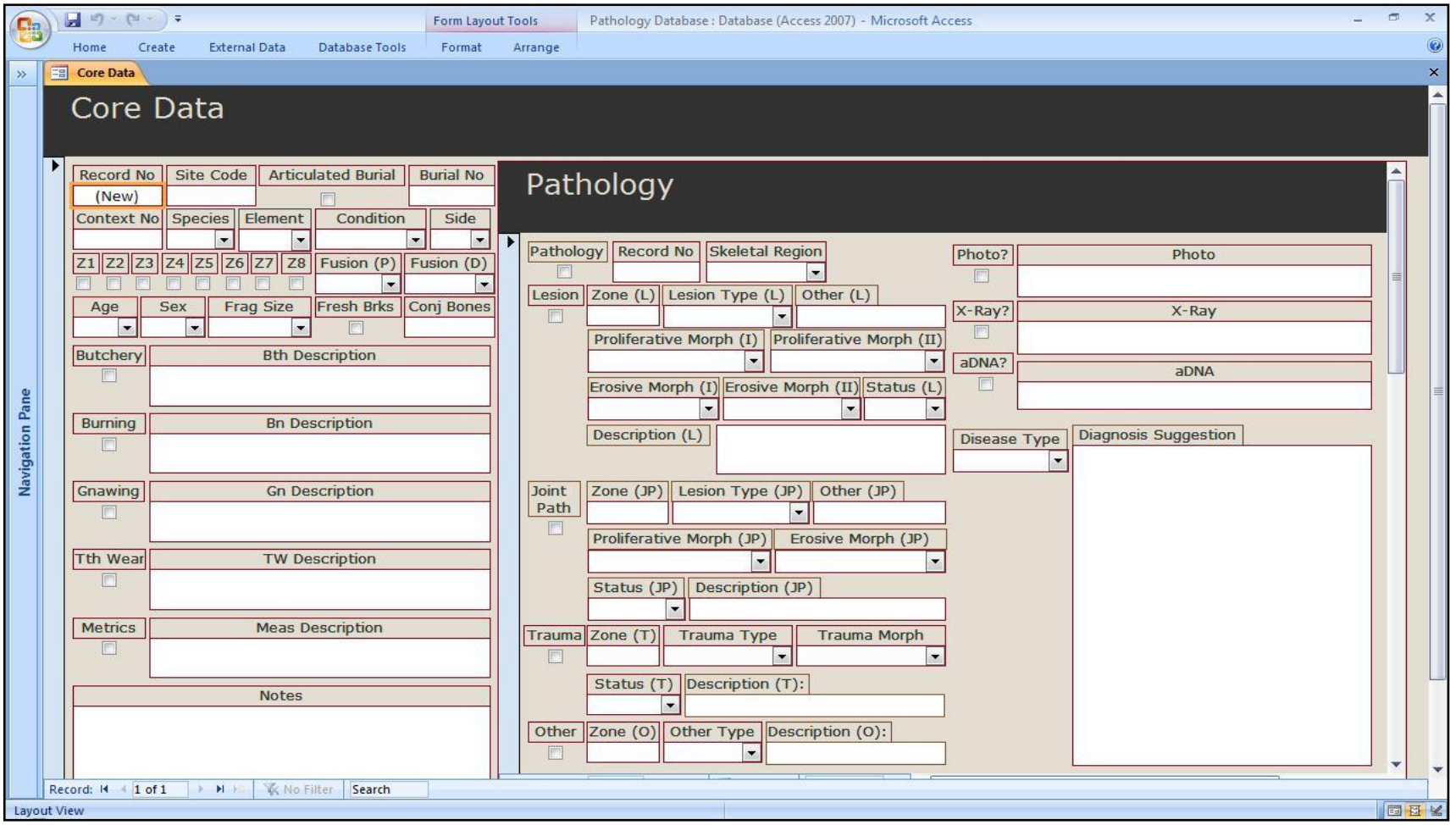


Figure 7.1 Basic Assessment Form

Those bones identified as pathological were recorded using the core data and pathology recording form also created using *Access.* As this method required the recording of standard zooarchaeological criteria for each pathological bone, two

separate forms were created and linked together: ‘Core Data’ and ‘Pathology’ (Figure 7.2).

Figure 7.2 Full Analysis Recording Form



Core Data Recording Form

The zooarchaeological criteria and information categories that were incorporated into the core data recording form (Figure 7.2) were outlined and discussed in section 7.2.1. It became apparent with the regular use of the core data recording form that some of the tick boxes, number boxes and drop-down menus were not required, for example, 'articulated burial' and 'burial number'. In the end, to ensure consistency, all articulated burials were recorded using the *Excel* spreadsheet that had been created to record the (section 7.4.1). Therefore, these boxes became redundant, along with the 'fragment size', 'age' and 'sex' boxes, which were used on occasion but found to be an unnecessary addition in this case. However, this was of no detriment to the research and only served to illustrate how the recording database could be fine-tuned in the future for better application to different assemblages with different research questions.

Pathology Recording Form

The pathology recording form was devised based upon the criteria outlined in section 6.3.1.2. The main aim of this form was to provide a detailed overview of the abnormality being recorded. Abnormalities that were of interest but not directly related to a possible infectious aetiology were still recorded in order to gain an overview of pathological alteration affecting each assemblage. However, less detail was given to these and those scoring systems that do exist to record certain alterations, such as activity-related change affecting the lower limbs of cattle (see

Bartosiewicz *et al.* 1997) and oral pathology (see Levitan 1985) were not implemented.

The form comprises four main sections: lesion, joint pathology, trauma and other. These are simplified sections but were considered sufficient to provide the detail required when accompanied by a large text box for the purposes of detailed description and suggestions as to possible aetiologies. The predilection sites associated with an infectious and systemic disease such as bTB include, most notably, the joints, but also non-specific lesions can also appear on the long-bone diaphyses, the visceral surface of the ribs, the pelvic basin and also the cranium. This is why 'lesion' and 'joint pathology' were chosen as two of the three main sections of the pathology recording form. The 'other' section included a drop-down menu to cover the types of alteration which were of lesser interest in this case: 'oral pathology', 'congenital', 'nutritional/metabolic' and 'other'.

Each of the main three sections consisted of a number of different descriptive categories with drop-down menus to further emphasise the specific abnormality identified. Each section contained a category referred to as either 'lesion type' or, in the case of trauma, 'trauma type'. The drop-down menus for these then provided a list from which to choose the best descriptor for the abnormality, for example, 'proliferative', 'erosive, 'fracture' etc. This was then followed by another series of descriptive categories focused upon the morphology of the abnormality:

'proliferative morphology', 'erosive morphology' and 'trauma morphology'. These again included drop-down menus to further expand upon the specific morphological characteristics of the abnormality. If a lesion was proliferative, what form did the lesion take? Was it woven bone or compact bone? Did it form a plaque, was it porous or did it possess spiculated bone? Each individual drop-down menu included slightly different descriptive labels tailored to each section, but in all there were two labels repeated: 'combination' and 'other'. In addition to identifying the type of abnormality and its morphology, each section also contained a drop-down menu labelled 'status'. This menu provided the means to record whether the abnormality was 'active', 'healed' or 'healing/partially healed'.

Alongside the individual sections, a series of tick boxes were included to indicate whether or not a photograph had been taken, or whether the particular bone merited an x-ray or aDNA sample. The final part of the form included a large descriptive text box to supplement the main sections of the form and another drop-down menu to identify (if possible) the disease type/category, for example, arthropathy, specific infection, non-specific infection, osteomyelitis, trauma etc. As with the zooarchaeology recording form, extensive use of this pathology recording form led to parts of it being used more than others. This was a combination of both limited experience with creating a database using *Access* and limited experience in the field of palaeopathology at the beginning of the research. For example, some of the chosen descriptive labels, in hindsight, were not ideal. However, any deficiencies identified in the design of the form did not hinder or mislead the

recording of any pathological bones, as the descriptive text box was used to fully describe each specimen, which was also photographed.

8. METHODS (II): THE APPLICATION OF MACROSCOPIC, MICROSCOPIC AND BIOMOLECULAR METHODS

'...it is clear that lesions due to tuberculosis will not easily be detected on animal bones from archaeological sites'

(Lignereux & Peters 1999: 347)

8.1 Introduction

This chapter focuses on the macroscopic, microscopic and biomolecular methods used to aid in the better understanding of bTB and its skeletal manifestation in archaeological faunal assemblages. The information available to zooarchaeological researchers, at present, is limited. A review of the medical and veterinary literature regarding the pathogenesis of bTB (see Chapter 3) highlights the general paucity of information available, reaffirming the need for research of this nature. As a result of modern day animal husbandry and tuberculin testing, there are understandably few (if any) readily available faunal reference collections containing 'known' tuberculous *skeletal* specimens (Lignereux & Peters 1999: 347). There is more information available in the pre-tuberculin era, specifically a small number of early 20th Century illustrations (see section 3.8), but nothing comprehensive. In an attempt to progress forwards and address the need for more information, it was acknowledged that an improved understanding of those lesions consistent with skeletal tuberculosis in animals was required. Therefore, a multidisciplinary approach was

developed, incorporating: skeletal lesion patterning (section 8.2), differential diagnosis (section 8.4), radiography (section 8.5) and ancient DNA (aDNA) analyses (section 8.6). These methods are commonplace in human palaeopathology and are integral to both medical and veterinary practice. They are applied here in order to establish a framework of reference for skeletal TB (specifically for cattle and pig), in addition to providing clarification regarding lesion distribution, lesion morphology and lesion specificity.

8.2 Macroscopic Method: Skeletal Lesion Patterning

Skeletal lesion patterning is well established in human palaeopathology; a diagnostic tool routinely employed and fundamental to differential diagnosis, as highlighted by numerous researchers (Mays 2005: 139; Roberts & Buikstra 2003: 118; Knüsel & Ogden 2007). As Knüsel & Ogden (2007: 1797) stated; '*Although bone response is not specific to particular disease pathogens, the patterning of lesions in the skeleton often is'.* In his text entitled *Paleopathological Diagnosis and Interpretation: Bone Diseases in Ancient Human Populations,* Steinbock (1976) included illustrations of the skeletal distribution of lesions associated with TB, leprosy and treponemal disease, amongst others (Figure 8.1). When viewed side by side, these illustrations are simple, yet extremely informative visual aids. Their re-use in a number of different texts is a testament to their successful application in human palaeopathology. However, skeletal lesion patterning is not a regularly applied palaeopathological method in zooarchaeology.

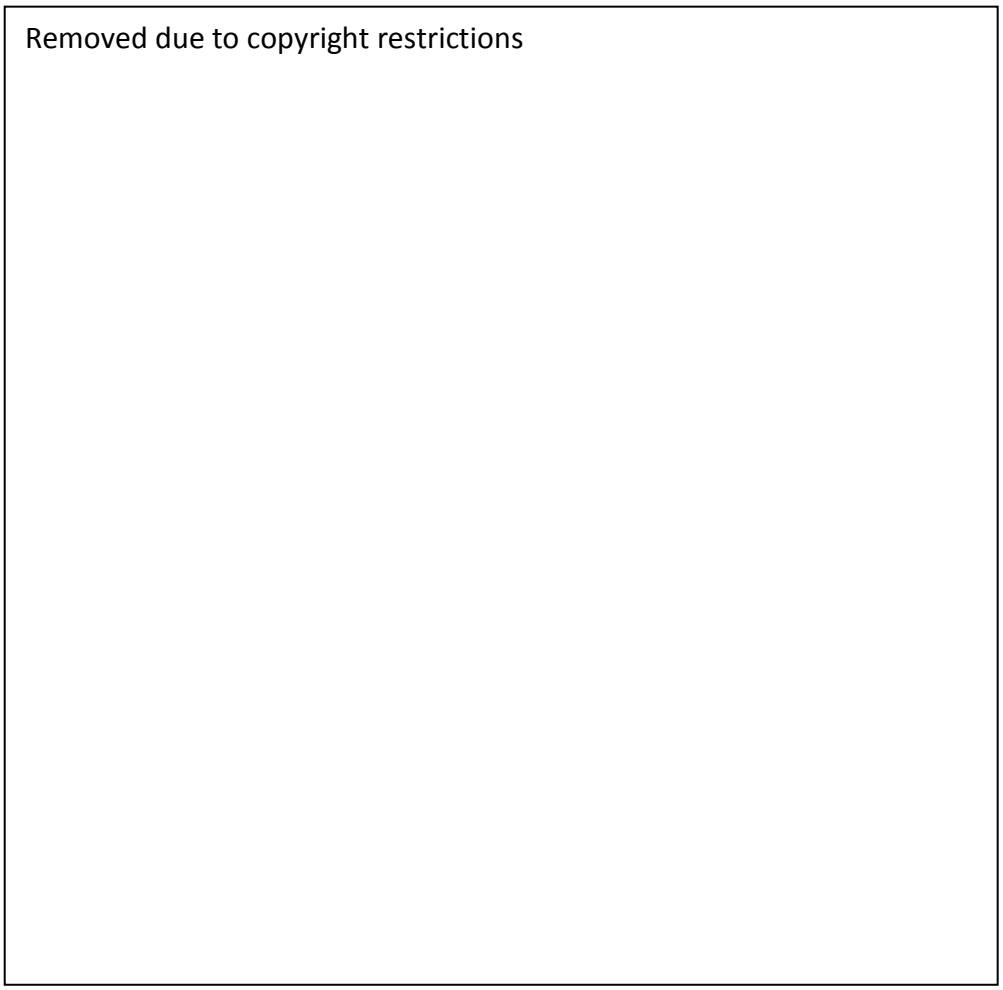


Figure 8.1 Skeletal lesion patterning associated with TB and Leprosy in humans (Steinbock 1976: Figure 69 & 76)

Articulated animal skeletons are a luxury not often encountered by zooarchaeologists, with pathological examples even rarer. The predominantly disarticulated and fragmented remains that comprise the majority of zooarchaeological assemblages preclude the observation and recording of pathological lesion distributions. For this reason, there is unfortunately neither the perceived need nor impetus to gain a thorough understanding of the skeletal lesion

distribution for different diseases in zooarchaeology and a regrettable lack of dissemination of data. Of those articulated animal skeletons excavated, only a few pathological examples have been published (see Bartosiewicz & Bartosiewicz 2002; Bathurst & Barta 2004; Bendrey 2004; Bendrey *et al.* 2008). Understandably, this has led to little in the way of research beyond the analysis of localised pathologies and as a result, broader questions related to past animal health, animal husbandry and animal management on both regional and temporal scales at the population level have gone unanswered (see Chapter 2).

8.3 Bovine tuberculosis in cattle, pigs and humans: Lesion distribution

The first stage to formulating a better understanding of the skeletal manifestation of bTB in animal bone (both articulated and disarticulated) was to illustrate the lesion distribution, highlighting the key predilection sites. Based upon the information presented in Chapters 3 & 4, attention was focused upon the following species: cattle, pig and human (Figures 8.2 & 8.3). The patterning of lesions associated with TB in the human skeleton is well established (see Steinbock 1976: fig 69 also illustrated above in Figure 8.1); however, as far as the researcher is aware, there are no comparable reference illustrations detailing the lesion distributions of diseases for different animal species. Therefore, two illustrations were compiled portraying those predilection sites associated with bTB in cattle and pig (Figure 8.2). These illustrations were based upon the descriptive information located in both the archaeological and veterinary literature (see Cohrs 1967, Lignereux & Peters 1999 and Mays 2005). As a zoonosis, the identification of bTB is

equally as important in human skeletal remains as it is in animals, therefore, the lesion distribution associated with TB in humans is also illustrated (Figure 8.3). Figure 8.3 is based upon Steinbock's familiar illustration (see Figure 8.1) along with the information presented in several texts (see Steinbock 1976; Ortner & Putschar 1985; Aufderheide & Rodriguez-Martin 1998; Ortner 2003; Roberts & Buikstra 2005 and Mays 2005). However, there have been some notable additions, specifically aimed at providing a more thorough overview of the lesion distribution associated with this disease in humans, along with highlighting those skeletal elements that (if affected) may indicate disease of a bovine origin. Through comparison with Steinbock's illustration in Figure 8.1, it can be seen that the cranium, sternum and ribs have not been shaded in his original. It is presumed that only the primary predilection sites were highlighted representing the standard/generic lesion distribution for this disease. This is understandable considering the fact that (as Steinbock himself states); '… *tuberculosis may involve any bone of the skeleton*' (Steinbock 1976: 176). However, in the re-created illustration, these elements were included, along with the pelvic girdle. It has been acknowledged that gastro-intestinal infection, as a result of MTB complex disease, could leave evidence on the internal aspects of these elements (Roberts & Buikstra 2003: 98). Gastro-intestinal TB does not automatically equate to an infection with *M. bovis* but, in some cases the ingestion of infected milk and meat or even the swallowing of sputum infected with *M. bovis* could result in pathological change within the pelvic girdle, along with the anterior surface of the sacrum, yet these skeletal elements are not often illustrated (section 3.11).

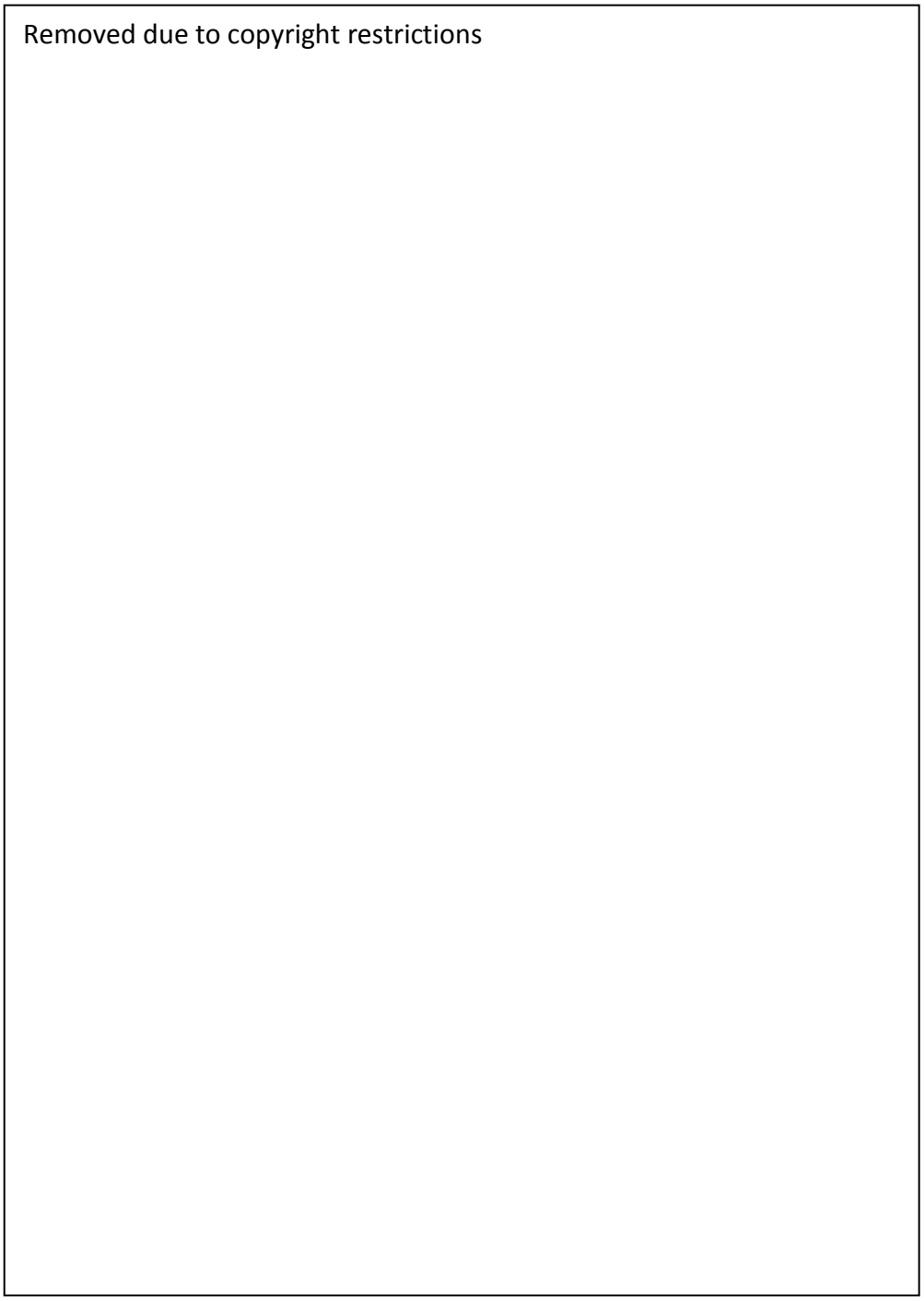


Figure 8.2 Skeletal lesion patterning of bTB in cattle and pig (Adapted from Wooding 2010, fig 12.3 & 12.4)

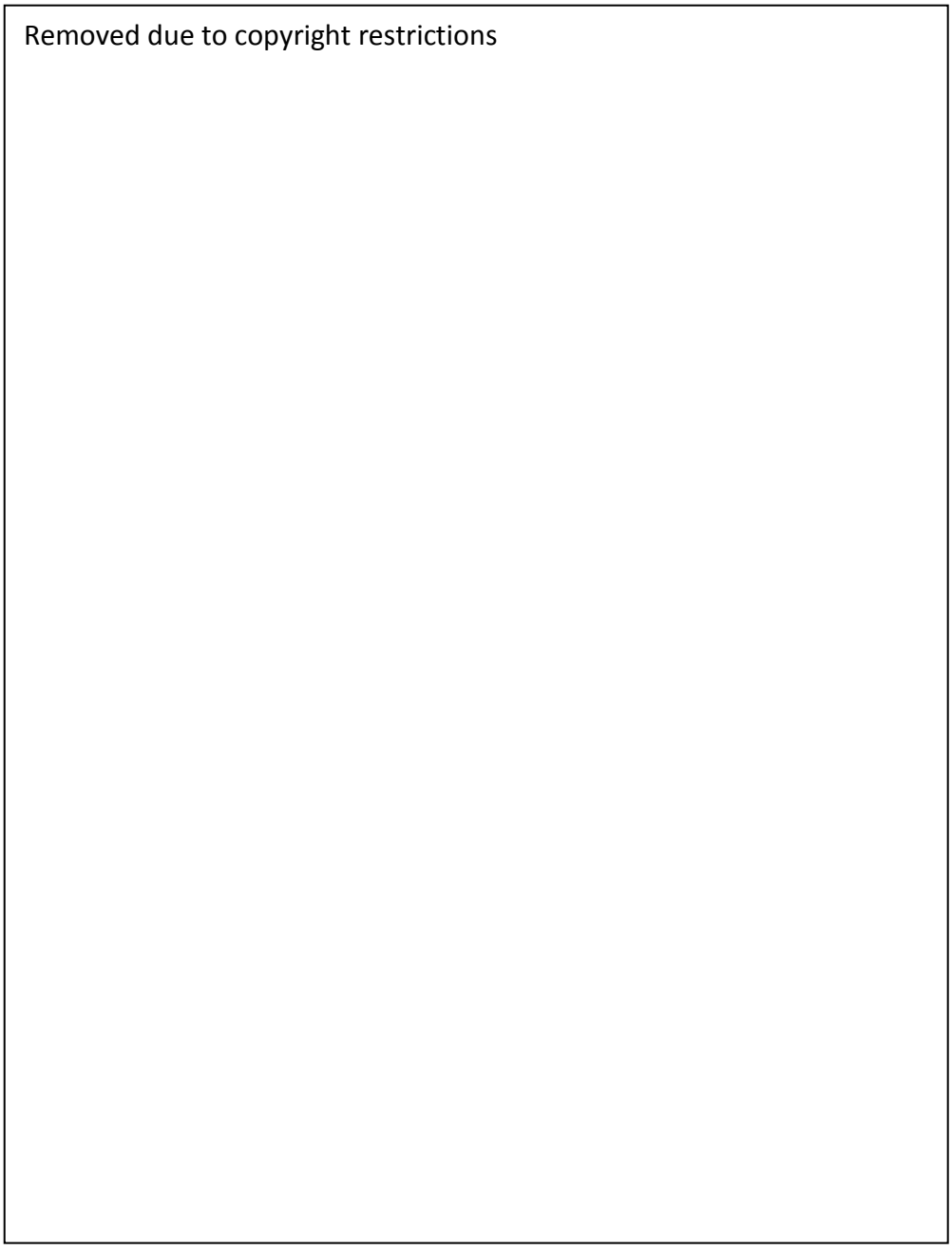


Figure 8.3 Skeletal lesion patterning of TB in humans (Adapted from Wooding 2010: fig 12.2)

8.4 Differential Diagnosis

The differential diagnosis of skeletal TB in both humans and animals was presented and discussed in Chapter 4. For the purposes of this research and to provide a useful point of reference for the analysis and contemplation of pathological lesions in the assemblages targeted for analysis (see Chapter 6), a series of summary/reference tables were created (see Chapter 4). The intention behind these tables was to present only the most pertinent information, forming a 'first port of call' for the zoopalaeopathologist. The reason for creating individual tables was simply based upon ease of use and formatting. These could easily be amalgamated into a reference booklet or a larger all inclusive table.

8.5 Radiography

Faunal bones with interesting pathological lesions and especially those deemed potentially infectious were radiographed by Dr. Jo. Buckberry (assisted by the author) using specialised facilities in the Division of AGES, University of Bradford. A Hewlett-Packard Faxitron industrial x-ray machine was used to radiograph the bones. In the early stages of this research, digital radiographs were taken using a Konica Minolta Regius 190 computed radiography (CR) system as this equipment was on loan to the division. Images were captured using image storage plates (storage phosphors), using 2 second exposures and beam energies ranging from 45-60 kV dependent upon the density of the bone. The image is stored on the plates in the form of trapped electrons. When scanned using a laser, the electrons become

free and release their excess energy in the form of light, which is subsequently detected and digitised. The plate is then erased and ready for reuse (O' Connor pers. comm.). In the later stages of this research, standard industrial radiography with film was used. To produce the best possible image, an exposure test was conducted using a cattle vertebra from the Danebury Hillfort assemblage. Exposure times ranging from 15 – 90 seconds were tested (Figure 8.4), with 60 seconds at 120 kV producing the most favourable image. Films were developed according to departmental laboratory protocols. The developed films were scanned using an Agfa FS50B industrial scanner and digitised using Radview capture software.

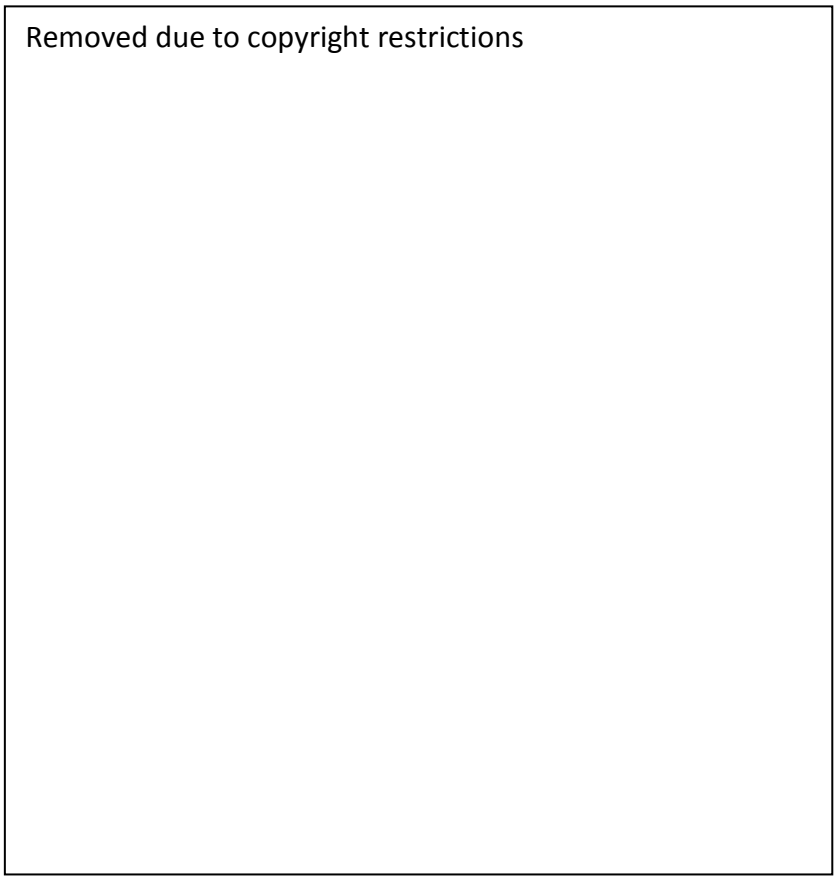


Figure 8.4 X-ray exposure test at 120 kV using Pb screen (X-ray: Dr. J. Buckberry)

8.6 Ancient DNA (aDNA) analysis

A total of 15 bones with lesions of a potential infectious aetiology were selected for further analysis based upon their pathological lesions. These were sent to Dr. G.M. Taylor at the Centre for Infectious Diseases and International Health, University College London (UCL) for aDNA analysis. A report outlining the method and results of this analysis (Taylor 2010, unpublished report) can be viewed in Appendix 3. A brief summary of the method involved is presented below based upon the information outlined in this report, previous publications and observations made by the author upon visits to UCL. Replication of the positive samples is currently being undertaken by Dr. Graham Stewart and Dr. Rachel Shrimpton, at the Division of Microbial Sciences, University of Surrey.

8.6.1 Sampling: A summary

Samples were taken either directly from the pathological lesion, or if this was not possible, a piece of bone was removed from within the vicinity of the lesion. The sampling although essentially destructive was, in fact, extremely minimal in terms of visible bone alteration. Pathological lesions were sampled using a sterile and disposable scalpel (Bendrey *et al.* 2008: 1586-7), whereby a portion of the affected area was scraped and then further ground into a fine bone powder using a sterile pestle and mortar. If a sample could not be obtained using a scalpel, then a small piece of bone was taken from an already broken edge and ground into a fine powder. Two separate sets of samples were taken from the bones, these were

weighed and placed within a sterile container (Bendrey *et al.* 2008: 1597). One sample was for the initial analysis at UCL and the second was for further replication (if necessary) at the University of Surrey. Samples varied in weight from 20mg – a maximum of 130mg dependant on the preservation and size of the bone and the extent of the pathological lesion (Taylor 2010: Appendix 3).

8.6.2 DNA Extraction, PCR methods and PCR amplification: A summary

DNA was extracted from the bone powder samples using a NucliSens kit from bioMérieux, with the specific method outlined in Taylor *et al.* 2006 and Taylor 2010 (Appendix 3). The DNA extracts were screened for MTB Complex organisms using PCR methods targeting the multi-copy element *IS1081* (see Taylor *et al.* 2005; Taylor 2010: Appendix 3 for more detailed discussion). PCR methods incorporating three primer combinations/templates were used to amplify DNA fragments of 135, 113 and 79 base pairs (bp) respectively (Taylor 2010: Appendix 3). In addition to this, the presence or absence of MTB Complex DNA was also investigated through amplification of the direct repeat (DR) region. This technique detects MTB Complex mycobacteria and aids in the classification of strain type. To simplify the process, two specific loci (spacers 23 & 38) were targeted as these are both present in the majority of UK *M. bovis* strains (Taylor 2010: Appendix 3).

The samples were also screened for Brucella DNA using IS*711* (Taylor 2010: Appendix 3). Brucellosis is one of the main differential diagnoses for bTB (section

4.2) in faunal bone and is also an important zoonosis, therefore, it was deemed important to target this disease alongside bTB.

In addition to pathogen DNA, Dr. G.M. Taylor also designed a number of primers to detect the presence of mitochondrial DNA (mtDNA), specifically targeting the specie specific cytochrome b (*cytb*) gene. This was undertaken for a number of reasons (see Appendix 3), the main one being to assess DNA preservation in the bone samples. This is especially important when analysing archaeological samples, which are subject to taphonomy and diagenesis.

Real-time PCR was applied to the targeted amplicons outlined above using a Corbett Rotor-Gene 3000 or alternatively using a Stratagene Mx3005P real-time platform (see Appendix 3). Automated DNA sequencing was performed to confirm or rebut products amplified from the cytochrome b gene and Brucella PCR methods. Alternatively, the small amplicons associated with the DR and IS*1081* methods were confirmed through probe hybridisation. The identification of specific mycobacterial strains was attempted through spoligotyping following Kamerbeek *et al*. (1997) (see Appendix 3).

8.6.3 Contamination control

Measures were taken to avoid potential sources of contamination and cross-contamination throughout the sampling and analysis. These have been outlined in

detail previously (see Taylor *et al.* 2006; Bendrey *et al.* 2008; Murphy *et al.* 2009) and are summarised by Taylor (Taylor 2010, unpublished report) (see Appendix 3).

8.7 Conclusion

This chapter has outlined the macroscopic, microscopic and biomolecular methods applied in this research, to attempt a better understanding of the location, morphology and potential specificity of skeletal lesions associated with MTB complex disease (specifically bTB), in zooarchaeological assemblages. These methods of analysis, specifically skeletal lesion patterning, differential diagnosis and radiography are routine in human palaeopathology. They have been implemented here in order to address the dearth of information available for zooarchaeologists regarding one specific disease (bTB), but also in order to assess the potential/viability of such methods to both articulated and disarticulated faunal assemblages.

THE IDENTIFICATION OF BOVINE TUBERCULOSIS IN ZOOARCHAEOLOGICAL ASSEMBLAGES

VOLUME 2 (2 OF 2)

J. E. WOODING

PhD

UNIVERSITY OF BRADFORD

2010

THE IDENTIFICATION OF BOVINE TUBERCULOSIS IN ZOOARCHAEOLOGICAL ASSEMBLAGES

Working towards differential diagnostic criteria

Volume 2 (2 of 2)

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Submitted for the degree of Doctor of Philosophy

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Division of Archaeological, Geographical and Environmental Sciences

University of Bradford

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9. PALAEOPATHOLOGICAL ANALYSIS OF ZOOARCHAEOLOGICAL ASSEMBLAGES: THE MACROSCOPIC, MICROSCOPIC AND BIOMOLECULAR RESULTS

9.1 Introduction

The following chapter presents the macroscopic, microscopic and biomolecular results of this research. The method of data analysis (section 9.2) and the statistical tests applied to the data (section 9.3) are outlined first. This is followed by the results of the modern case studies (section 9.4), the Iron Age sites (section 9.5-9.7), the Viking Age sites (section 9.8-9.11), the aDNA results (section 9.12) and the summary focused on inter and intra-site comparisons (section 9.13).

9.2 Data Analysis Method

Two specific types of table are used to display the palaeopathological results for each assemblage. The first table focuses on presenting the different types of pathological change evident on each affected bone. Some bones exhibit multiple pathological conditions and some just a single example. They are recorded individually here (unless obviously combined) to demonstrate the spread of bone change by bone across the assemblages. The categories used in this first table have been adapted from Ortner (2003) and are defined below:

- **Proliferation**

Any abnormal bone formation, including: periosteal/sub-periosteal new bone, endosteal new bone and osteophyte/enthesophyte/syndesmophyte formation. If an area of proliferation is associated with a fracture callus, this is recorded in 'other'.

- **Lysis**

Any abnormal bone loss, including: porous, lytic lesions, cystic lesions, space-occupying lesions, pitting and porosity, cortical clefts/fissures and lesions associated with *osteochondrosis manifesta* (OCM). Lesions associated with the latter are referred to here as OCM as opposed to *osteochondrosis dissecans* (OCD) after suggestions for the implementation of this terminology (see O'Connor 2008).

- **Shape**

Any abnormal shape or dysplasia that is not related to an obvious fracture.

- **Size**

Any bone or tooth that exhibits abnormal size (either too large or too small) that is not associated with an obvious fracture. Enlarged foramina are included within this category.

- **Mixed Lesions**

  Pathological conditions that are directly related to each other, for example: fracture followed by callus formation or by infection and bone loss/deposition.

- **Other**

  Any pathological conditions that do not fit into the above categories, including: fracture, abnormal attrition, excessive calculus, alveolar recession, ante-mortem tooth loss and eburnation.

The second table focuses on categorising the pathological conditions into broad groups based upon suspected aetiology. This is in order to elicit a crude prevalence rate by assemblage and species. The categories used are defined as follows:

- **Oral pathology**

  Any pathological condition affecting the dentition or associated mandible and maxilla, including: periodontal disease, abnormal attrition, abscess and excessive calculus. The exception to this is osteoarthrosis of the temporomandibular joint, which is recorded under ‘arthropathy’.

- **Trauma**

  Any condition that is traumatic in origin, for example, fracture, ossified haematoma and enthesopathies.

- **Arthropathy**

Any pathology associated with the joints, including: osteoarthrosis (comprising joint contour change, extension of the articular surface through exotoses and osteophyte formation, pitting and porosity, eburnation and subchondral cysts), spondylosis deformans (osteophytes/syndesmophyte formation). Arthropathies can be the result of infection or trauma as well as degeneration, but unless this can be definitively identified, arthropathy is recorded.

- **Congenital**

Any pathology or abnormality that is perceived to be congenital or developmental in origin, such as: supernumerary teeth, absent teeth, perforation of the occipital bone (see Brothwell 1996) and polydactyly (see Murphy 2005: 11-12).

- **Infection (Non-specific bone proliferation & non-specific bone lysis)**

Specific infection is impossible to identify in disarticulated and fragmented bones; therefore, only non-specific cases of either bone proliferation or bone lysis can be recorded. Not all isolated cases will be due to infection; some may be associated with trauma, non-infective conditions such as neoplasia, or bone cysts.

- **Mixed Lesions**

Any bone that exhibits multiple lesions that are clearly associated, for example trauma followed by infection or trauma followed by arthropathy.

- **Other**

  Any pathological condition with an aetiology that has not been assigned a category, including: *osteochondrosis manifesta* (OCM), neoplasia and metabolic/nutritional conditions/disorders. In addition, any condition that is unable to be categorised.

The numbers recorded in both tables differ from each other and from the total number of pathological bones recorded. In some instances, there are multiple pathological conditions affecting a single bone, some of which may share a general aetiology, for example trauma. Some may possess different aetiologies, for example trauma and congenital, and some may share a combined aetiology, for example trauma and infection.

9.3 Statistical analyses

Comparative statistical analyses were conducted on the data, where possible. As the data was categorical, chi-square (X^2) was selected as the most appropriate statistical test. Two versions of the test were implemented, a standard two sample test (2 x 2 contingency table) and a one sample test (goodness of fit). The statistics software program *Statistica* (version 9) was used to conduct the analyses. All hypotheses and data tables are presented in Appendix 4. It was not possible to run statistical analyses on all of the data due to a number of limitations. In two cases - Danebury Hillfort (section 9.7) and Hrisheimer (section 9.11) - the full faunal assemblage was not analysed, either because it was not available or due to time constraints. Therefore, the palaeopathological data was derived from a sample of

the assemblage and, therefore, is unlikely to be representative. In addition, only the data pertaining to cattle and sheep/goat was compared. This is because these two species were most frequently identified as pathological and thereby allowing for a more thorough comparative analysis of the differences between these particular species. For each site deemed appropriate for statistical analysis, cattle and sheep/goat aetiologies were compared using 2 x 2 contingency tables. Not all aetiologies were comparable due to low data scores. The main aim of this analysis was to highlight any significant differences in the frequency of non-specific bone proliferation and bone lysis between cattle and sheep/goat at $\alpha = 0.05$.

Non-specific bone proliferation and bone lysis was further explored using the one sample 'goodness of fit' test. The skeletal distribution of lesions associated with possible infection was the focus of this analysis. Due to the low frequency of these lesion types for each individual species, all species, including the unidentifiable categories of LTM and MTM were combined to make the data viable. As the pathogenesis of infectious diseases, such as bTB, in animals is broadly similar (section 3.6), the amalgamation of the data in this manner was not deemed overly detrimental to the analysis. Two versions of this test were conducted. The first focused on all four skeletal regions recorded: oral, cranial, axial and appendicular. The second focused on just the axial and appendicular regions. The main aim for both tests was to identify significant differences in the distribution of these lesion types throughout the skeleton, the operant hypothesis being that the lesions would be expected to be equally distributed. As it was noted that the greater majority of these lesions were recorded in either the axial and appendicular regions, further

tests were employed to specifically target these regions in greater detail. This was an important factor to explore, considering the fact that infectious diseases, such as bTB, primarily target the cancellous bone of the axial and appendicular skeleton (section 8.3). Therefore, these further tests were focused on these two skeletal regions in order to highlight potential patterns/preference in lesion type and location. The summation of the number of lesions recorded per skeletal region was divided by the number of regions recorded and this was used as the expected value. These tests were conducted only on those sites where there was enough data to produce an expected value of at least five to render the test statistically viable. The distribution of pathological lesions in association with the ABGs at Wetwang Slack and Danebury Hillfort were also subject to this analysis.

As well as conducting intra-site comparisons of cattle and sheep/goat, a series of inter-site comparisons focused upon comparing cattle vs. cattle, sheep/goat vs. sheep/goat and cattle vs. sheep/goat were also conducted to highlight any significant differences in species at different sites and over different time periods (Iron Age/Romano-British vs. Viking Age/Norse). Four sites were selected for inter-site analysis: Wetwang Slack and Barton Field (Iron Age/Romano-British) and Hofstaðir and Sveigakot (Viking Age/Norse). Danebury, Hrisheimer and Westness were excluded from this analysis. The first two sites were excluded for the reasons already mentioned above. Westness was excluded because it was completely un-phased. Arguably, the same can be said for Barton Field, Tarrant Hinton, however, at the latter site, there was a greater preponderance of data. Also, the two phases identified at Wetwang Slack (Iron Age and Iron Age/Romano-British) were

amalgamated to ensure comparability with the Iron Age/Romano-British faunal assemblage associated with Barton Field, Tarrant Hinton. For the Viking Age sites, Hofstaðir is later in date than Sveigakot, however, the occupation at both sites does overlap and this difference in date also provides an additional angle from which to interpret any differences in the palaeopathological data.

9.4 Modern Case Studies

As a part of this research, modern faunal material from animals with lesions suspected of being infective in origin were targeted for analysis. Four articulated skeletons were selected for further analysis: a pig, two badgers and a red deer skeleton. In addition to this, disarticulated bones from a modern pathological collection (The Baker Collection) curated at the University of York were also analysed. The articulated skeletons and two bones from the Baker collection were recorded, photographed and sampled for aDNA analysis by Dr. G. M. Taylor (section 9.12). These case studies are presented below.

9.4.1 Case Study: Pig (*Sus domesticus*), Chester

This specimen comprises a juvenile pig aged between 1 year and less than 2 years (12 - <17-22 months) at death. This age-at-death estimation is based upon epiphyseal fusion and tooth eruption data. The pig was recovered as part of a police investigation in woodland near to the city of Chester. It is not known how the pig died or exactly when it was deposited, but it is not thought to be any older than 200 years (Smith pers. comm.). Unfortunately, as the skeleton was removed in haste, it was not possible to recover it in its entirety. The pathological lesions are predominantly destructive and appear generalised, involving both the axial and appendicular skeleton (Table 9.1, Figure 9.1).

Table 9.1 Frequency of lesion types recorded for Pig ABG

Pig	Frequency of Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
Pig, Chester	2	15	-	-	1	-

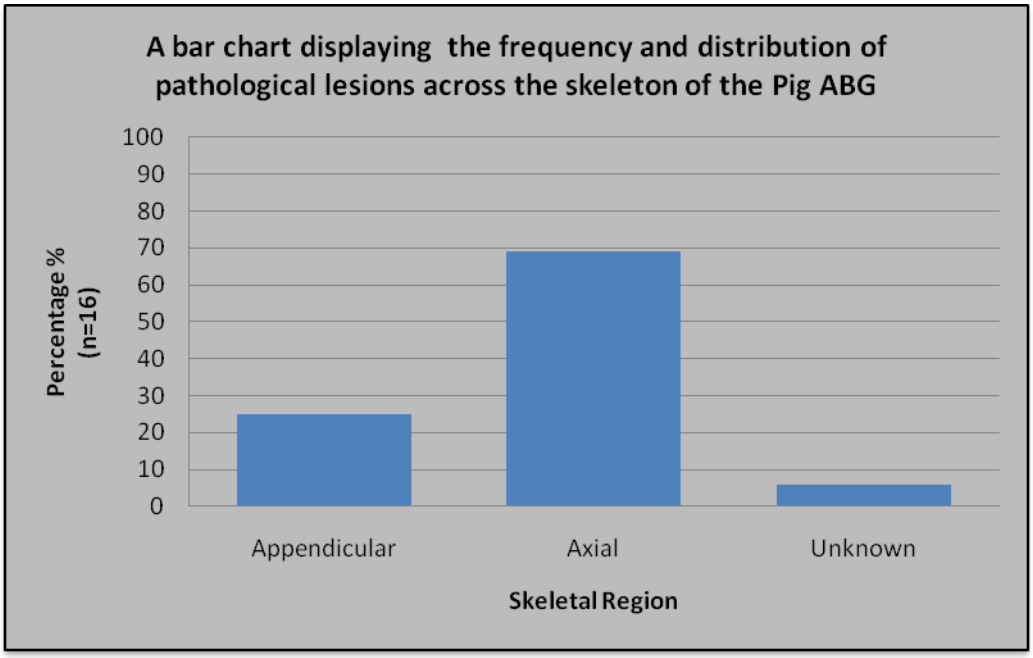
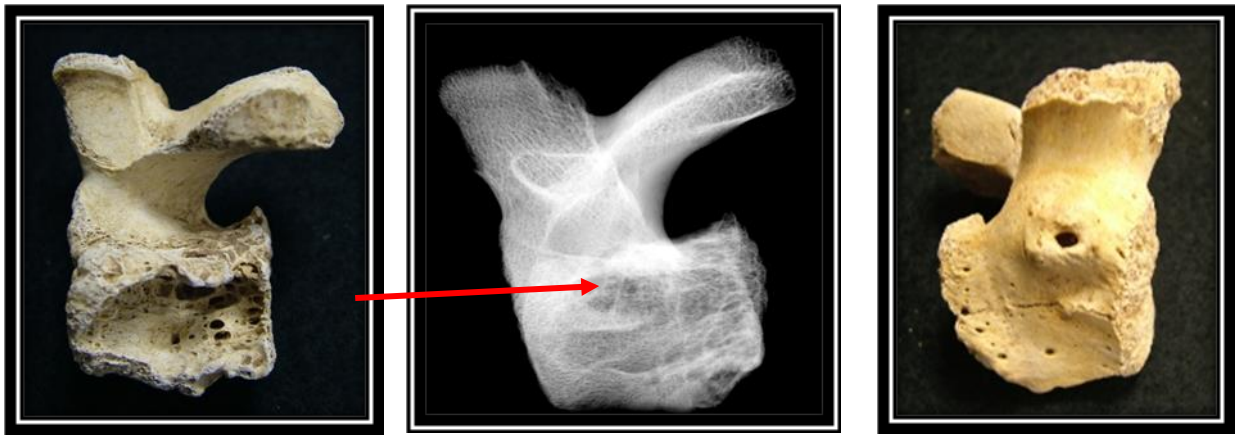


Figure 9.1 Pig ABG: The distribution of lesions by skeletal region

Eighteen pathological lesions were recorded on 16 bones. Over half of these (69%) were located in the axial skeleton and comprised both abnormal bone proliferation and abnormal bone lysis. A quarter of the lesions (25%) were located in the appendicular skeleton. These consisted of abnormal bone lysis and a mixed lesion displaying both bone proliferation and bone lysis.

The majority of the lesions recorded consisted of abnormal bone lysis (83%). The axial skeleton and specifically the lumbar vertebrae were the most frequently

affected. Large space-occupying lesions were identified in three lumbar vertebrae bodies, one of which was associated with a large cloaca (Figure 9.2). These lesions possessed smooth, remodelled and sclerotic margins, indicating a chronic condition despite the young age of the pig.



a b c

Figure 9.2 Pig lumbar vertebra with a large space-occupying lesion (a, b), accompanied by a cloaca (c). The radiograph displays a clear sclerotic margin (b) (Photo: Author, Radiograph: Dr. Alan Outram, Prof. C.J. Knüsel)

Another lumbar vertebra displayed porous, lytic lesions within the vertebral foramen and multiple cloacae perforating through to the outer surface. If this bone was fragmented as the others had been, it is likely that another large space-occupying lesion would have been present. A small plaque of woven bone (periostosis) was also observed on the underside of the transverse process in this bone, possibly associated with the exudate passing through the cloacae (Figure 9.3).

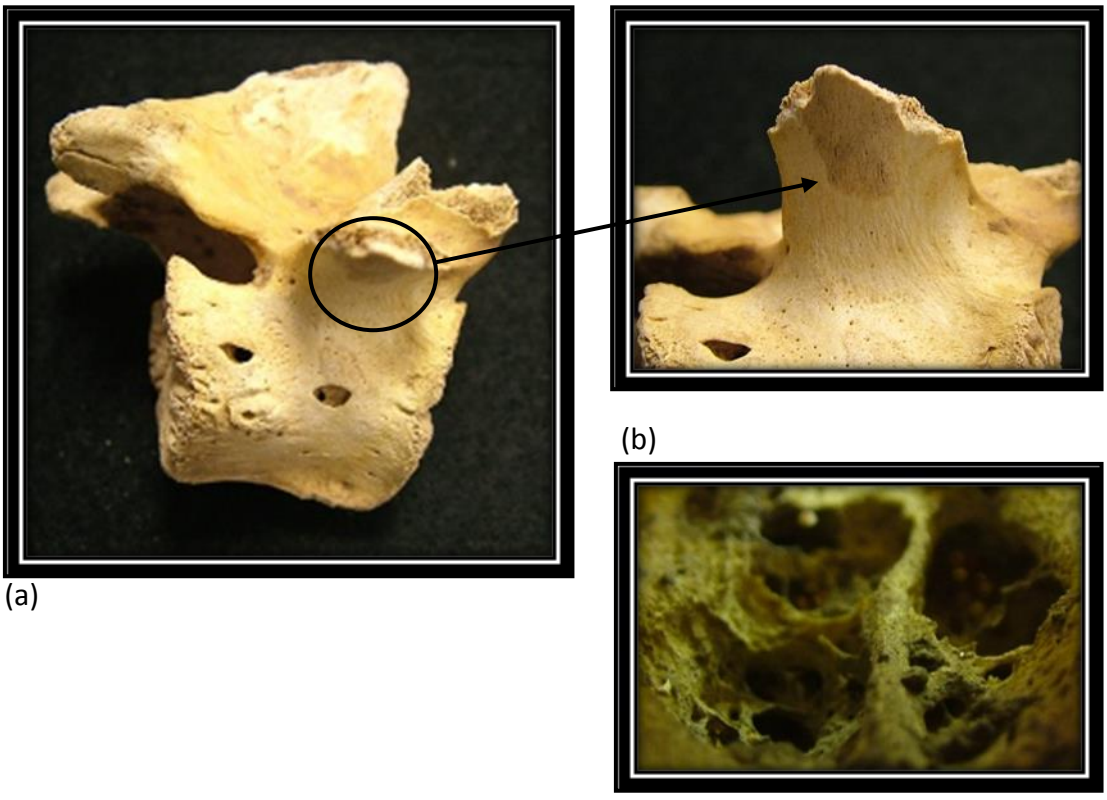


Figure 9.3 Pig lumbar vertebra displaying loss of bone within the vertebral foramen (c), in association with three cloacae (a) and periostosis (b) (Photo: Author)

Another lumbar vertebra displayed an irregular resorptive lesion destroying a part of the neural arch and inferior part of the base of the spinous process (Figure 9.4). This latter bone very much resembles the 20th Century image of a tuberculous focus in a pig thoracic vertebra (see Figure 3.13, section 3.8.5).

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(a) (b)

Figure 9.4 Pig lumbar vertebra with resorptive lesion affecting the neural arch and base of the spinous process (a) (Photo: Author). This is potentially the result of an abscess similar to that illustrated in the 20th century pig thoracic vertebra image (b, indicated at c on diagram) (Ostertag 1922: 602 cited in Lignereux and Peters 1999:fig. 6)

A further lumbar vertebra displayed two small space-occupying lesions affecting the unfused vertebral body surface (Figure 9.5). These lesions are similar to those observed at Danebury Hillfort (see Figure 9.107)

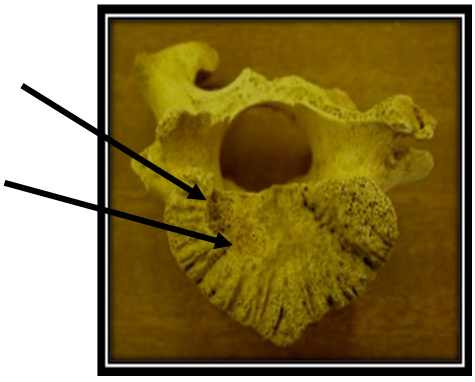


Figure 9.5 Pig lumbar vertebra with space-occupying lesion located on the unfused vertebral body (Photo: Author)

A mixed lesion was identified in the appendicular skeleton affecting the neck of the scapula and consisting of both proliferative and lytic lesions (Figure 9.6). A large space-occupying lesion is present on the medial facing side of the neck running up to just beneath the glenoid fossa. This lesion has smooth, remodelled margins and the interior of the cavity is also smooth. Around one side of the lesion is compact new bone formation. At the base of the lesion there are smaller nodules of compact new bone. The blade on both the medial and lateral sides appears unaffected as does the unfused articular surface.

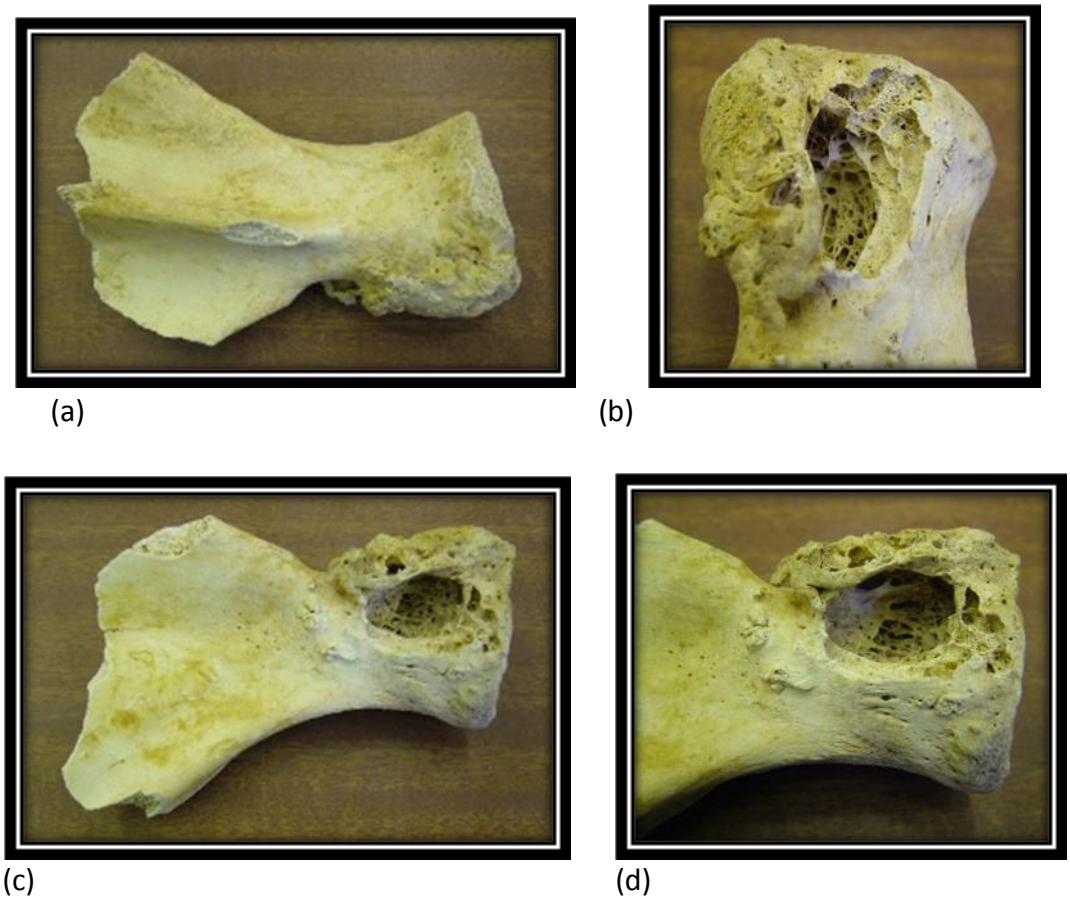


Figure 9.6 Pig scapula displaying a large space-occupying lesion with compact new bone formation. The space-occupying lesion is located on the medial side of the neck (b, c and d). The compact new bone formation surrounds half of the lesion (view a) and also appears as bony nodules (d) (Photos: Author)

Further lesions were observed in the pelvis (proliferation and lysis), a rib (lysis) and two carpals/tarsals (lysis).

Summary and Differential Diagnosis

The lesions observed in this pig ABG are extremely destructive, but also display proliferative new bone formation as well as sclerosis. Multiple lesions affecting many parts of the skeleton would appear to indicate a generalised chronic infective process. The lesions present in the lumbar vertebral bodies, especially those with cloacae are the result of osteomyelitis. This could be a non-specific pyogenic osteomyelitis or osteomyelitis associated with a specific infection, the prime candidates being either: MTB Complex or brucellosis (*B. suis*). Through comparison with the skeletal lesion patterning illustration compiled for *Mycobacterium bovis* in pigs (Figure 8.2), it is evident that the primary predilection sites associated with this disease are involved in the pig ABG from Chester. Therefore, MTB complex is one of the main differential diagnoses for this ABG and is the reason why it was selected for aDNA analysis (section 9.12). Brucellosis may possibly be ruled out because it is reported that *B. suis* is not present in modern day pigs in the UK (see Boden 2005). However, this pig may be up to 200 years old, so the possibility cannot be entirely ruled out.

9.4.2 Case Study: Badger (*Meles meles)*, Wessex

This case study comprises an adult male badger (Figure 9.7). The badger was found as roadkill and was incorporated into the zooarchaeological reference collection at Wessex Archaeology (Grimm pers. comm.). The skeleton is complete and displays both proliferative and destructive lesions, involving both the appendicular and axial skeleton (Table 9.2, Figure 9.8).

Figure 9.7 Articulated post-cranial badger skeleton displaying trauma to the left side of the skeleton presumably associated with manner of death (road accident) (Photo: Author)

Table 9.2 Frequency of lesion types recorded for Badger ABG

Badger	**Frequency of Lesion Type**					
	Proliferation	**Lysis**	**Shape**	**Size**	**Mixed Lesion**	**Other**
Badger, Wessex	5	9	-	-	2	-

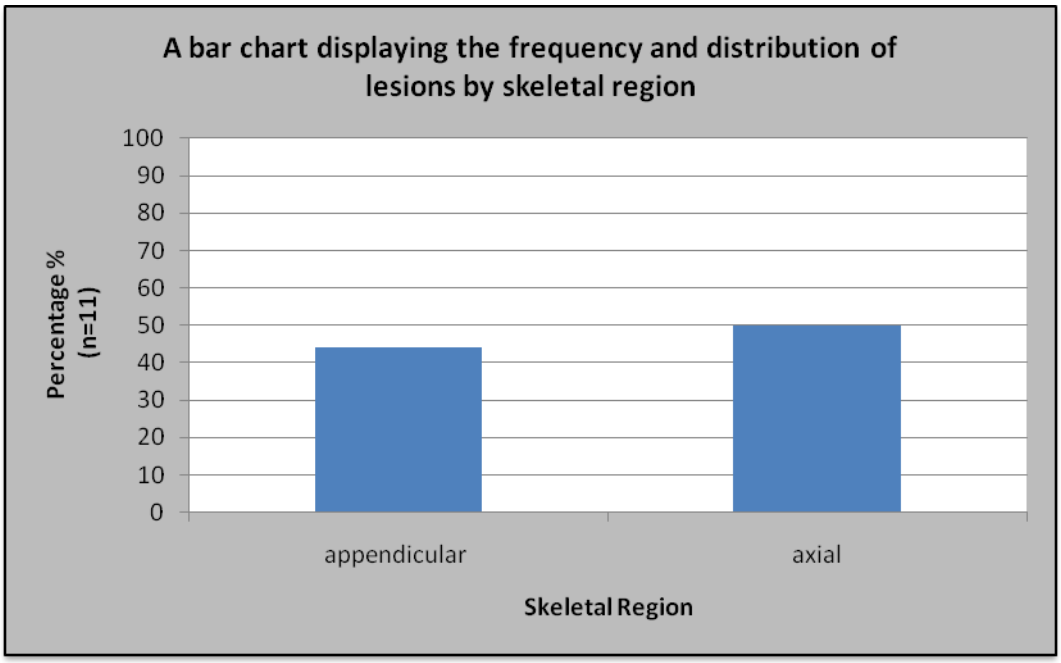


Figure 9.8 Badger ABG: The distribution of lesions by skeletal region

Sixteen instances of pathology were recorded on this badger ABG. Half of the lesions recorded (50%) were located in the axial skeleton and consisted of abnormal bone proliferation, abnormal bone lysis and mixed lesions. The remaining lesions were located in the appendicular skeleton (44%) and comprised both abnormal bone proliferation and abnormal bone lysis.

The majority of the lesions recorded consisted of abnormal bone lysis (56%). An example of this was the presence of bilateral porous lesions on the proximal humeral heads. These lesions were also mirrored by proliferative lesions on the glenoid fossae of both scapulae (Figure 9.9).

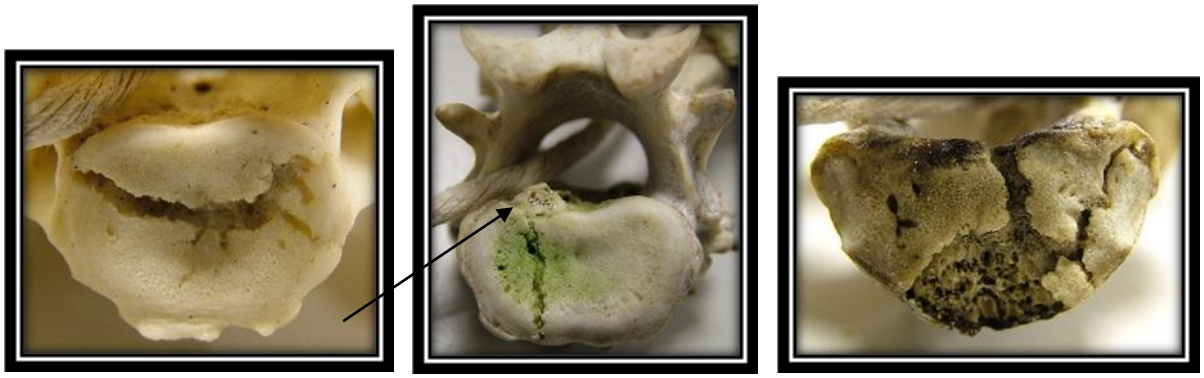
a b

Figure 9.9 Bilateral periostosis on surfaces of glenoid fossa (a), accompanied by bilateral porous lesions on both humeral heads (view b) (Photo: Author)

A small lytic lesion was also identified in the left radius, affecting the proximal lateral shaft. The right-hand side of the sacrum was absent (Figure 9.10), but it is difficult to ascertain whether this was the result of pathology or taphonomy. There is evidence for trauma in the skeleton, particularly on the left side. Therefore, one possibility for this missing piece is a peri-mortem fracture, possibly associated with the manner of death. The loose bone may have been lost during burial and/or subsequent curation.

Figure 9.10 Ventral view of the sacrum with missing right half (Photo: Author)

A cervical vertebra displayed a curious lytic 'channel' with irregular edges running horizontally across the caudal vertebral endplate (Figure 9.11, view a). This does not appear to be taphonomic but may be trauma-related as the badger was discovered as roadkill. A further example was noted on a lumbar vertebra, but this time the 'channel' was vertically oriented (Figure 9.11, view b). This vertebra also possessed a compact bony nodule within the vertebral foramen (see black arrow). This may be associated with intervertebral disc damage and may even be calcified disc material. A thoracic vertebra displays what could be a more advanced case of the same two previous conditions (Figure 9.11, view c).



a b c

Figure 9.11 Lytic lesions affecting the cervical (view a), thoracic (view c) and lumbar vertebra (view b) epiphyses (Photos: Author)

Another possibility is osteochondrosis. Similar channels in human vertebrae are illustrated by Swedbord (1975) and attributed to osteochondrosis (Swedbord 1975: Fig 1).

The last two caudal vertebrae display irregular lytic lesions in the centre of the vertebral endplates, perforating the bone and forming possible space-occupying lesions within them (Figure 9.12).

Figure 9.12 Caudal vertebra displaying lytic space-occupying lesion within the vertebral body and perforating the vertebral endplate (Photo: Author)

The two mixed lesion cases recorded affect the last thoracic vertebra (T14) and the first lumbar vertebra (L1) (Figure 9.13). The articular vertebral endplates display pitting and eburnation. Ossification of the anterior longitudinal ligament is evident in the formation of syndesmophytes on both the ventral and lateral vertebral bodies. Large bony spurs have formed on the lateral sides of the L1 but although these projected across the body of the T14, they were not ankylosed at death. There also appears to be a gap on the ventral bodies where the two vertebrae articulate. The syndesmophyte formation on both sides has not extended at this point like the lateral examples. This may be associated with the ventral herniation of the intravertebral disc or a soft-tissue space-occupying mass (a possible paradiscal lesion associated with TB). The pathological lesions observed on these vertebrae are localised to the T14 and L1.

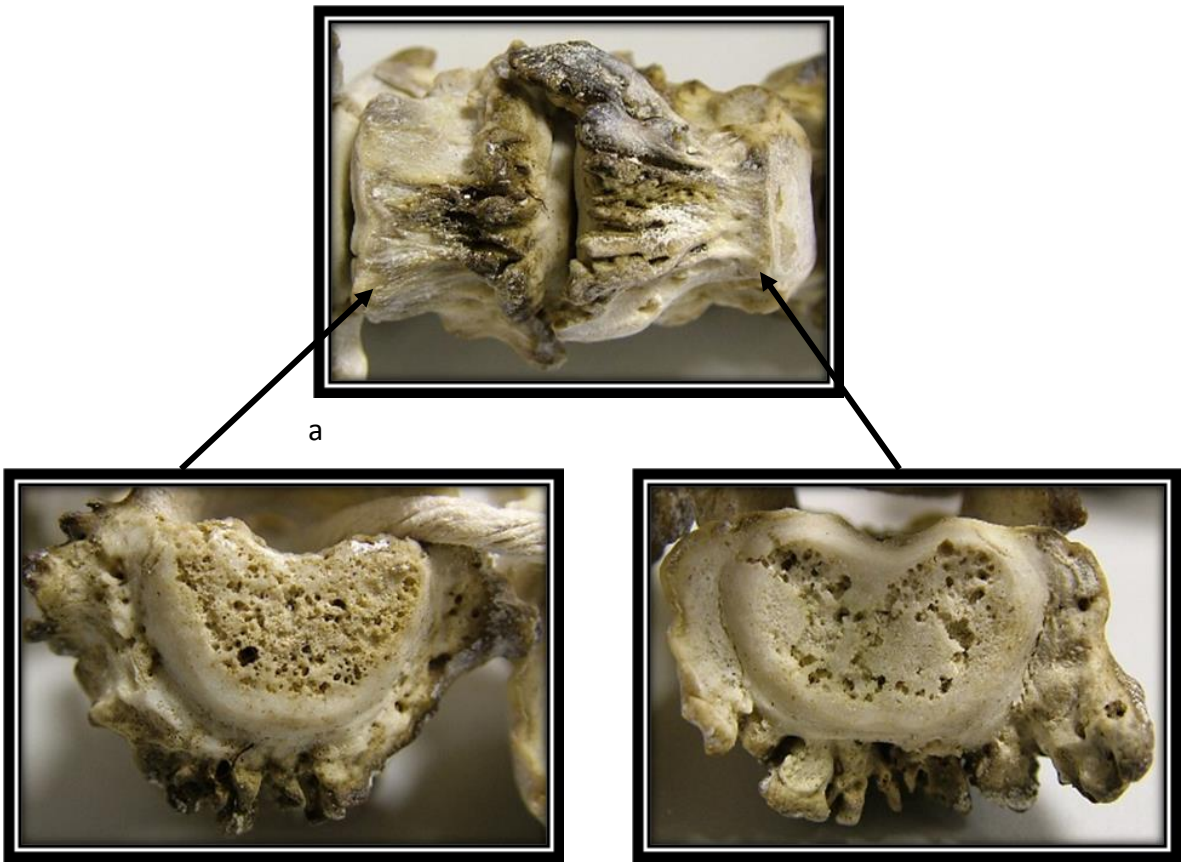


Figure 9.13 Last thoracic and first lumbar vertebrae displaying combined pathological lesions: eburnation and macroporosity of the vertebral endplates and marked syndesmophyte formation on the lateral and ventral vertebral bodies (Photos: Author)

Both ulnae also displayed osteophyte formation around the proximal articulation indicating bilateral arthropathy.

Summary and Differential Diagnosis

The lesions affecting this badger are varied and suggest a number of different aetiologies, of which infection could be included. Arthropathy is indicated through the presence of bilateral osteophytes affecting the ulnae. Bilateral porous, lytic and

proliferative lesions were also observed on the scapulae and humeral heads. If viewed in isolation, the lytic lesions affecting the humeral heads may be associated with osteochondrosis, a developmental defect, localised infection or early stage arthropathy. However, the fact that they are bilateral and are associated with bilateral localised patches of periostosis on the surfaces of each glenoid fossa indicates a symmetrical pathological condition affecting the forelimbs. This could represent a generalised arthropathy, although the presence of new bone formation on the surface of the glenoid fossa is intriguing and may point towards inflammation and infection in both joints. However, bilateral infection possessing near-identical lesions appears unlikely and the extent of bone destruction was slight which would tend to rule out an infective process. Therefore, arthropathy and developmental defect would be the prime candidates in this case. The lytic lesions affecting the radius and caudal vertebrae may indicate an infective process, especially in the latter where space-occupying lesions were identified. However, the rest of the vertebral column was unaffected by similar lesions, so this may have been localised infection affecting the tail, possibly associated with trauma. The irregular 'tunnelling' lesions affecting the cervical, thoracic and lumbar vertebral endplates could be associated with osteochondrosis or intervertebral disc damage. Lastly the combined lesions observed on the thoracic and lumbar vertebrae could be associated with either early stage spondylosis deformans or an inflammatory process such as diskospondylitis (Palmer 1993: 157). Alternatively, the lesions could be associated with septic arthropathy caused by a specific infection such as *M. bovis*. This is the reason why this badger was submitted for aDNA sampling (section 9.12). The pitting and eburnation affecting the vertebral endplates could support

either aetiology and would appear associated with degeneration of the annulus fibrosus.

9.4.3 Case Study: Badger (*Meles meles)*, Cambridge

This specimen comprises an adult, possibly female badger. It is unknown how this animal died. The badger forms part of the zooarchaeological reference collection at the University of Cambridge and was loaned for study by Dr. Jessica Rippengall. The skeleton is complete and displays widespread proliferative and destructive lesions, involving both the appendicular and axial skeleton (Table 9.3, Figure 9.14).

Table 9.3 Frequency of lesion types recorded for Badger ABG

Badger	**Frequency of Lesion Type**					
	Proliferation	**Lysis**	**Shape**	**Size**	**Mixed Lesion**	**Other**
Badger, Cambridge	19	11	-	-	21	-

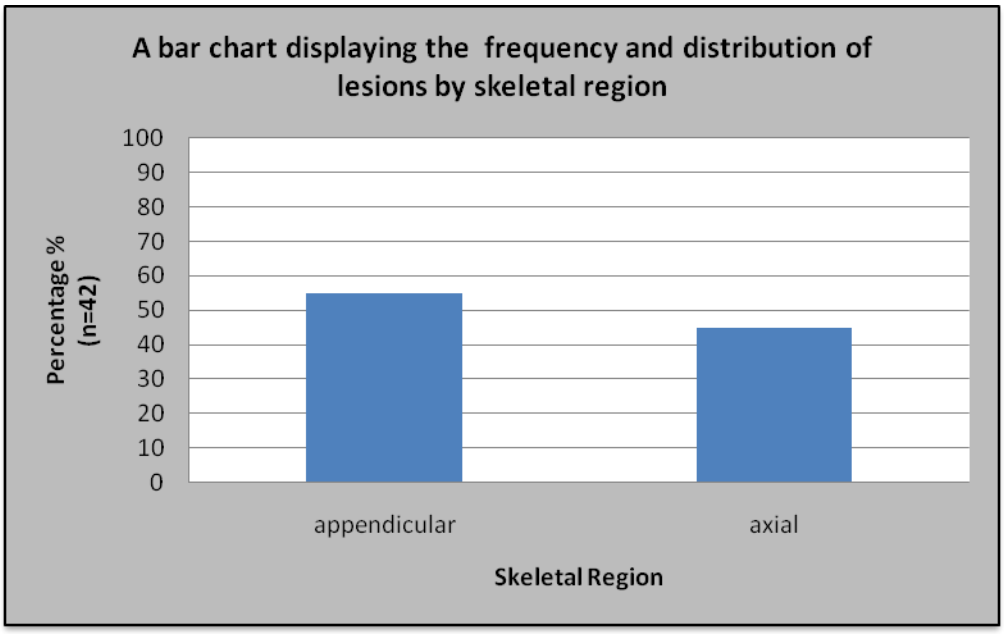


Figure 9.14 Badger ABG: The distribution of lesions by skeletal region

Fifty-one instances of pathology were recorded on 42 bones of this badger ABG. The majority of lesions were present on the appendicular skeleton (55%) and were predominantly associated with abnormal bone lysis (65%). The remaining lesions were associated with abnormal bone proliferation (17%) and mixed lesions (17%). Lesions on the axial skeleton totalled 45% and consisted largely of mixed lesions (63%). All of these were associated with the vertebral column. The remaining lesions were abnormal bone proliferation (15%) and abnormal bone lysis (22%).

Mixed lesions were recorded on both the axial and appendicular skeleton, but it is those on the axial skeleton that are most striking. The individual vertebrae possessed mixed proliferative and lytic lesions but when viewed together it is clear that the lesions all contribute to a pathological condition/process that was widespread throughout the vertebral column. Ossification of the anterior longitudinal ligament is evident on the ventral surface of the vertebral bodies, forming syndesmophytes. These are present on the cervical, thoracic and lumbar vertebrae, in addition to the sacrum (Figure 9.15), in some cases forming large bony spurs/bridges. These are not ankylosed. Some of the rib heads also displayed a mix of osteophyte/enthesophyte formation, presumably associated with the pathological alteration affecting the vertebral column. The epiphyses in a number of the affected vertebrae also display pitting, eburnation and bone lysis, of which some could represent subchondral cysts (Figure 9.16).

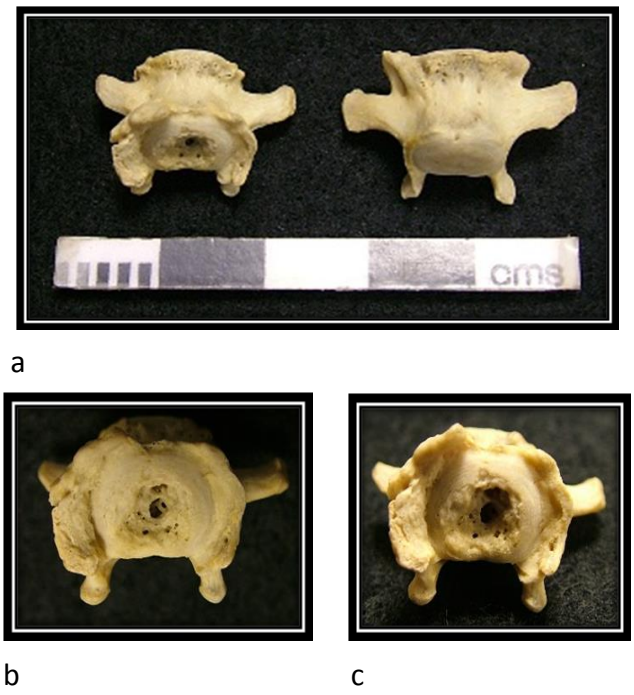
a b

Figure 9.15 Syndesmophyte formation affecting the cervical, thoracic and lumbar vertebrae (a), with close-up view of a syndesmophyte uniting two vertebral bodies (b) (Photos: Author)

a b c

Figure 9.16 Syndesmophyte formation affecting the lumbar vertebral bodies (a, b, c), in association with macroporosity eburnation and cystic lesions (subchondral cysts) affecting the epiphyses (Photos: Author)

Two lumbar vertebrae also possess a circular perforating, lytic lesion on the vertebral endplate (Figure 9.17). At the centre of these circular lytic lesions is a smaller circular lesion extending inferiorly into the vertebral body.



a

b c

Figure 9.17 Two lumbar vertebrae with paradiscal syndesmophyte formation (a) with perforating lytic lesions affecting the vertebral endplates (b, c) (Photo: Author)

Space-occupying lesions were also noted in all the caudal vertebrae, sometimes both vertebral endplates were affected and sometimes just the cranial or caudal endplates displayed destruction. The lesions were irregular in form but space-occupying lesions appear to have been present inside the caudal vertebral bodies (Figure 9.18). The lesions shown here are remarkably similar to those observed in the badger from Wessex (section 9.4.2, Figure 9.12).

Figure 9.18 Caudal vertebra displaying space-occupying lesion perforating the epiphysis (Photo: Author)

A series of small lytic lesions or perforations were also noted on three thoracic vertebrae (T13-15) (Figure 9.19). These are most pronounced in this region, although there are similar instances in a number of the lumbar vertebrae.

Figure 9.19 Thoracic vertebrae (T13-15) displaying multiple lytic perforations affecting the neural arches (Photo: Author)

Also on the T14, a localised patch of compact periostosis was identified on the cranial articular facets (apophyseal joints) (Figure 9.20).

Figure 9.20 Thoracic vertebrae (T14) displaying compact periostosis on the cranial articular facets (Photo: Author)

A number of other skeletal elements in the appendicular skeleton displayed abnormal bone proliferation, abnormal bone lysis and combined lesions. The majority of the abnormal bone proliferation was osteophyte and enthesophyte formation associated with the limb bone articulations. For example, both patellae displayed enthesophyte formation and both the left and right astragalus displayed bilateral eburnation and grooving.

Summary and Differential Diagnosis

The lesions affecting this badger are widespread and would appear to suggest generalised degenerative arthropathy. The badger was an elderly individual as the teeth were extremely worn. Although the pathology in the vertebral column may represent a degenerative spondyloarthropathy (*spondylosis deformans*), the lytic

lesions and periostosis would indicate the presence of a possible infective process. The irregular, lytic lesions affecting the caudal vertebrae may represent infection related to trauma in the tail region. These lesions appear localised to this region, as they were in the badger from Wessex. The pitting, eburnation and possible subchrondral cysts affecting the vertebral endplates are associated with arthropathy, however, these may have had an infective origin as the larger lytic lesions displayed in Figure 9.18 would appear to suggest. The compact periostosis on the neural arch of T14 also suggests either infection or localised trauma, especially as the new bone is localised to the region where the spinous process articulates with the neural arch. The multiple lytic lesions affecting the neural arch of T13-15 are intriguing and do not appear to be associated with infection as the holes are roughly equal in size and there is no associated new bone. These may also reflect a developmental defect. This badger was submitted for aDNA analysis based upon the combination of lesions present in the vertebral column (section 9.12).

9.4.4 Case Study: Red Deer (*Cervus elaphus*), Oxford

This case study comprises an adult female red deer aged at least 7-8 years at death. The animal became mired in a peat bog on Dartmoor and now forms part of Dr. Julie Hamilton's zooarchaeological reference collection at the Research Lab for Archaeology, University of Oxford. The skeleton is complete and displays widespread, generalised proliferative and destructive lesions, involving both the appendicular and axial skeleton (Table 9.4, Figure 9.21).

Table 9.4 Frequency of lesion types recorded for Red Deer ABG

Red Deer	Frequency of Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
Red Deer, Oxford	6	6	-	-	33	1

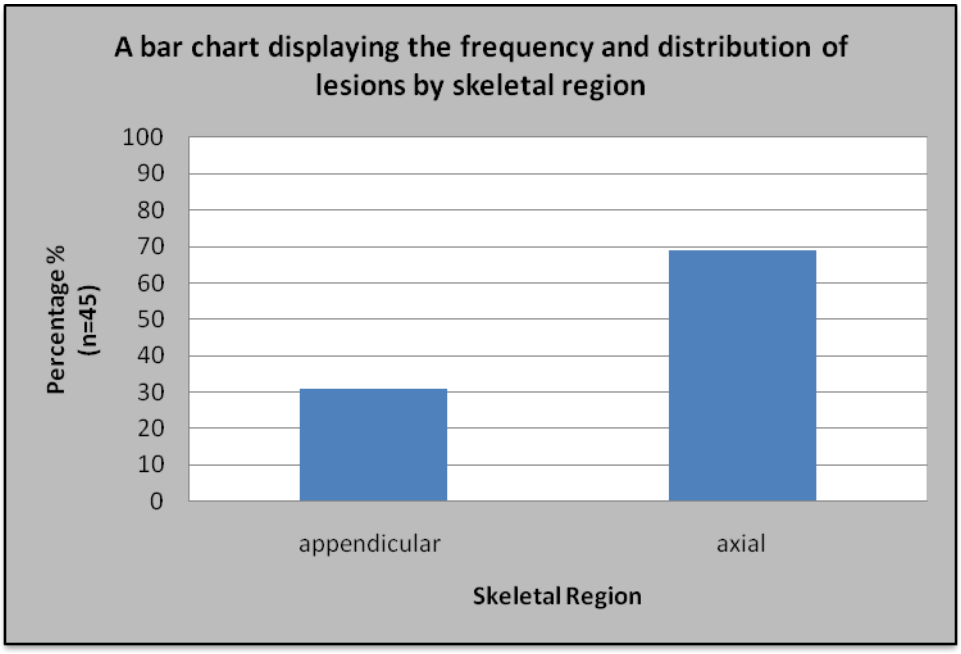


Figure 9.21 Red Deer ABG: The distribution of lesions across the skeleton

Forty-six instances of pathology were recorded on 45 bones of this red deer ABG. The majority of lesions were present on the axial skeleton (69%) and were predominantly associated with mixed lesions (84%). The remaining lesions were associated with abnormal bone lysis (13%) and one lesion recorded as 'other' (eburnation) (3%). Lesions on the appendicular skeleton totalled 31% and consisted of abnormal bone proliferation (43%), mixed lesions (43%) and abnormal bone lysis (14%).

The greater majority of this red deer skeleton displayed pathological change. Mixed lesions were recorded on both the axial and appendicular skeleton but like the badgers those affecting the axial skeleton were the most striking. The vertebrae when recorded individually possessed mixed proliferative and lytic lesions but when viewed together the lesions all contribute to the same pathological condition/process that affected the entire vertebral column from the atlas vertebra down to the sacrum and pelvis. The cervical, thoracic (and associated ribs) and lumbar vertebrae all displayed degenerative change including: eburnation of the epiphyses and articulating facets, joint contour change, pitting and cystic lesions affecting the vertebral endplates (Figure 9.22), porous, lytic lesions within the vertebral foramen, marked osteophyte formation around the cranial and caudal articular facets, spinous process and endplates and ossification of the ventral longitudinal ligament (Figure 9.23), the interspinous ligament and in some cases the intertransverse and interarcuate ligaments leading to substantial syndesmophyte formation and complete ankylosis of the T9 and T10 vertebrae, T11-L1 vertebrae (Figure 9.24) and the pelvis and sacrum (Figure 9.25).

Figure 9.22 Thoracic vertebra displaying eburnation and extensive destruction of the cranial endplate (pitting and cystic lesions) (Photo: Author)

a b

Figure 9.23 Ossification of the ventral longitudinal ligament forming an extensive syndesmophytes (a). Also extensive pitting of the caudal endplate (b) (Photo: Author)

a b

Figure 9.24 Ankylosis of T9 and T10 through ossification of the interspinous ligament(a). Also ankylosis of T11-L1 through ossification of the interspinous and intertransverse ligaments (b) (Photos: Author)

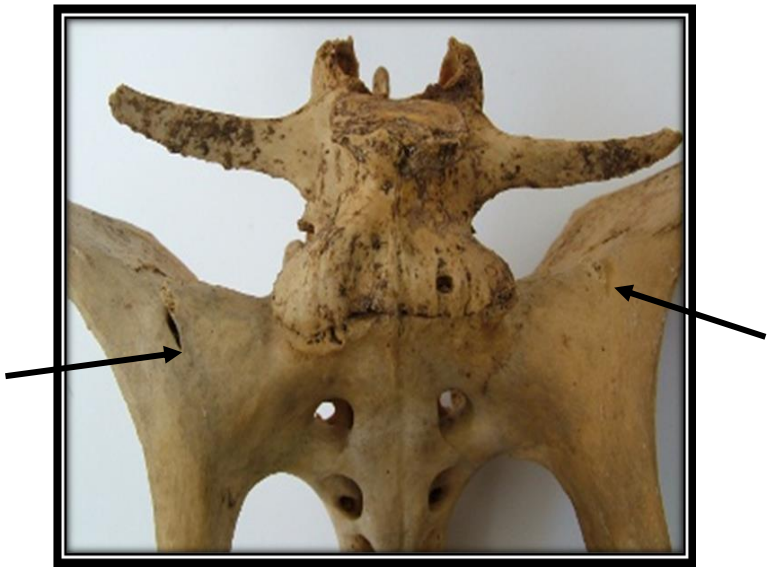


Figure 9.25 Ossification of the sacro-iliac ligament leading to ankylosis of the sacrum and ilia (arrows indicate nearly obliterated joint surfaces). Syndesmophyte formation on the ventral body of the L6, projecting towards and uniting with the sacrum, although there was no ankylosis at this point (Photo: Author)

In addition to these pathological changes, there also appears to be some displacement of the vertebrae, specifically involving the C7 and T1. These two vertebrae display the most pronounced abnormalities with destruction and eburnation of the endplates but also extensive new bone proliferation forming pockets around the cranial and caudal articular facets. These 'pockets' of new bone illustrates that the T1 and T2 (not shown) had probably slipped and were unstable. This particular region in the red deer is the point where the forces acting on the vertebrae change with the changing curvature of the neck. This may explain why these two vertebrae display such specific pathological changes on the neural arch (Figure 9.26).

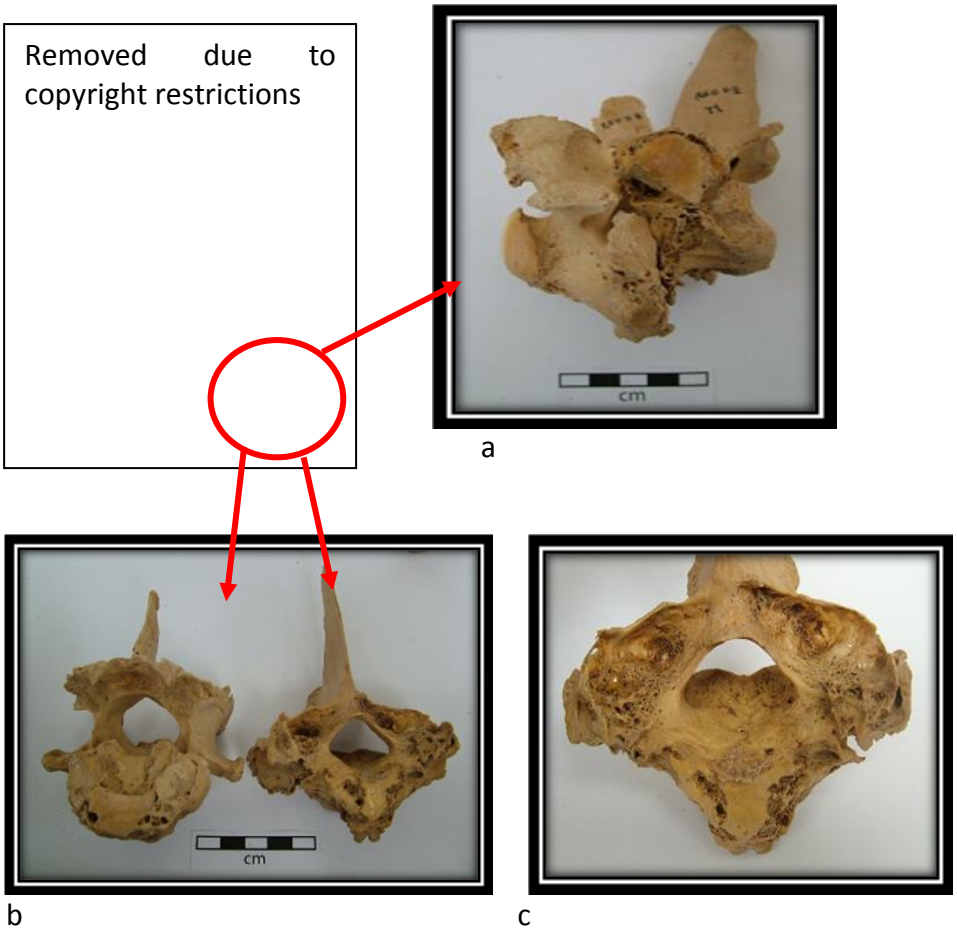


Figure 9.26 Pathological lesions affecting the C7 and T1 vertebrae associated with instability in the joint (a). Exotoses of new bone are present around the cranial and caudal articular facets (b, c) (Kumar *et al.* 2000: fig 1b, with additions; Photos: Author)

Extensive pathological change was also observed in the axial and appendicular skeleton affecting the pelvis and femur, specifically the joint region. Proliferative compact new bone (osteophyte formation) surrounds the periphery of the acetabulum with the interior displaying heavy pitting and eburnation (Figure 9.27, view c). This eburnation is mirrored on the femoral heads. However, there is further abnormal bone lysis affecting the proximal femur between the femoral head and the greater trochanter (Figure 9.27, view a). When the pelvis and femur are

articulated and viewed as a unit, the extent of the compact new bone formation and the bone lysis is evident (Figure 9.27, view b). The bone destruction on the proximal femur is not directly associated with the articular surface, suggesting that there was a possible soft tissue mass/infective focus possibly associated with the joint region and muscles surrounding it.

a b c

Figure 9.27 Abnormal bone proliferation and bone lysis associated with both the acetabulum (c) and the proximal femur (a). The articulation of these elements displays the extent of the new bone proliferation (b) (Photos: Author)

Further abnormal bone lysis was recorded in the sternum (Figure 9.28). Two circular perforating, lytic lesions were observed, with remodelled margins located in the xiphoid process. These lesions completely perforate the sternum and appear localised to it. They may simply represent sternal foramina and a developmental defect, but the level of remodelling would suggest an infective process.

a b

Figure 9.28 Perforating, lytic lesions in the xiphoid process (Photo: Author).

Osteophyte formation was noted in most of the appendicular bones including the scapulae, tibiae, metapodia, carpals, tarsals and patellae. Both tarso-metatarsal joints had completely ankylosed. Lytic lesions representing osteochrondrosis were also noted on the proximal medial facets of both metacarpals.

Summary and Differential Diagnosis

The lesions affecting this red deer are severe and widespread. Almost every joint was affected in some way. This indicates a generalised degenerative arthropathy (*spondylosis deformans*), very similar to ankylosing spondylitis in humans (section 4.6.3). Ankylosis was apparent in both the axial and appendicular skeleton and movement must have been severely restricted and painful. This explains how the animal became mired in the first place. The red deer appears to have been elderly based upon the tooth wear, which would fit well with the appearance of generalised arthropathy as a study on degenerative lesions in moose and white-tailed deer also indicated (see Wobeser and Runge 1975).

This red deer ABG was selected for aDNA analysis along with the pig and two badgers. The reason behind this choice was to see if this type of degenerative arthropathy could possibly have been instigated by a specific infection, such as MTB Complex, or whether MTB Complex could have been responsible for the additional bone lysis affecting the proximal femur. The latter does not appear associated with arthropathy so could potentially indicate the presence of infection surrounding the region of the hip joint, possibly associated with the degenerative change or completely separate from it. If infection was present in the hip joint resulting in a

septic arthritis, more pronounced destruction of the femoral head and acetabalum would be expected as it would also be expected if this was the case in the vertebral column. Therefore, the presence of a soft tissue focus/possible abscess outside the region of the joint is more promising.

9.4.5 The Baker Collection

The Baker Collection is a modern disarticulated faunal assemblage comprising pathological domestic and wild species. This collection is currently housed at the University of York. The majority of the assemblage, focusing specifically on the domestic remains, were recorded and photographed. Two bones were highlighted for aDNA sampling: a pig scapula and a horse rib.

9.4.5.1 Pig (Sus scrofa domestica) scapula

This pig scapula belonged to a juvenile pig, less than 12 months at death based upon the unfused glenoid fossa. The glenoid fossa has been completely destroyed by a space-occupying lesion. The articular surface has been hollowed out leaving a circular cavity with smooth but pitted and roughened margins. Sclerosis is evident on the radiograph (Figure 9.29).

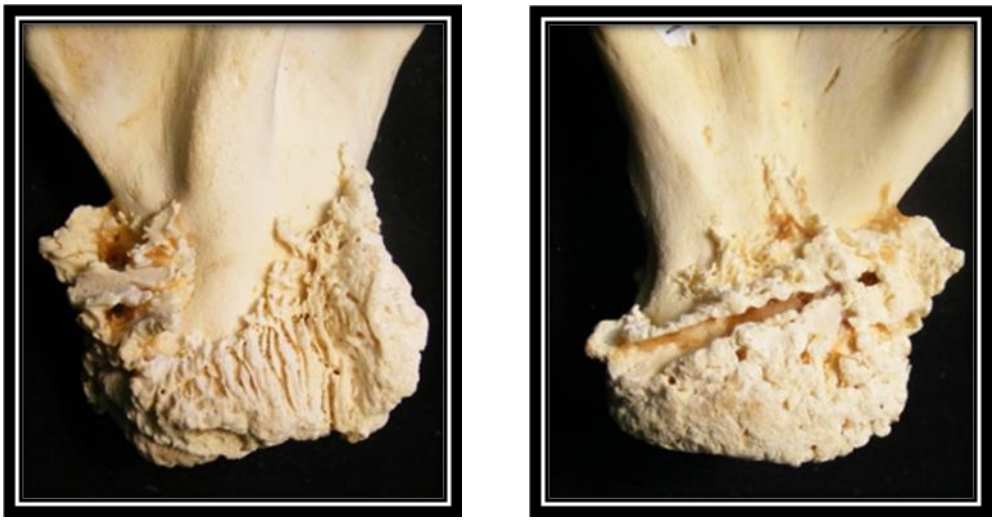
b

Removed due to copyright restrictions

a c

Figure 9.29 Pig scapula with space-occupying lesion located in the glenoid fossa (a). The articular surface has been completely destroyed (b) and a sclerotic margin is evident on the radiograph (c) (Photo: Author, X-ray: Dr. J. Buckberry)

Compact exuberant new bone proliferation surrounds the neck of the scapula. On the medial side of the neck, this has formed around a blood vessel which has left a channel through the bone (Figure 9.30).



a b

Figure 9.30 Lateral (a) and medial sides of the scapula neck displaying exuberant compact new bone proliferation and a channel running through it (b) (Photos: Author)

Summary and differential diagnosis

The report card which accompanied this scapula described the pathological lesions as 'septic arthritis of the scapula'. The aetiology of septic arthritis is non-specific; a bacterium or bacterial infection is the predominant causative agent (section 4.6.1). It is notoriously difficult to differentially diagnose tuberculous arthritis from septic arthritis, especially in disarticulated remains (Ortner 2003: 222). This scapula resembles the scapula from modern pig, Chester (section 9.4.1). The lesions are located in slightly different locations but the space-occupying lesion, compact new

bone proliferation and sclerotic response is all very similar. Therefore, this scapula from the Baker Collection was selected for aDNA sampling.

9.4.5.2 Horse (*Equus caballus*) rib

This horse rib is in two fragments, however, when articulated they reveal the presence of osteomyelitis. A large space-occupying lesion has formed in either side of the two exposed rib ends. In addition to this, there is swelling of the bone, a cloaca and a pathological fracture (Figure 9.31).

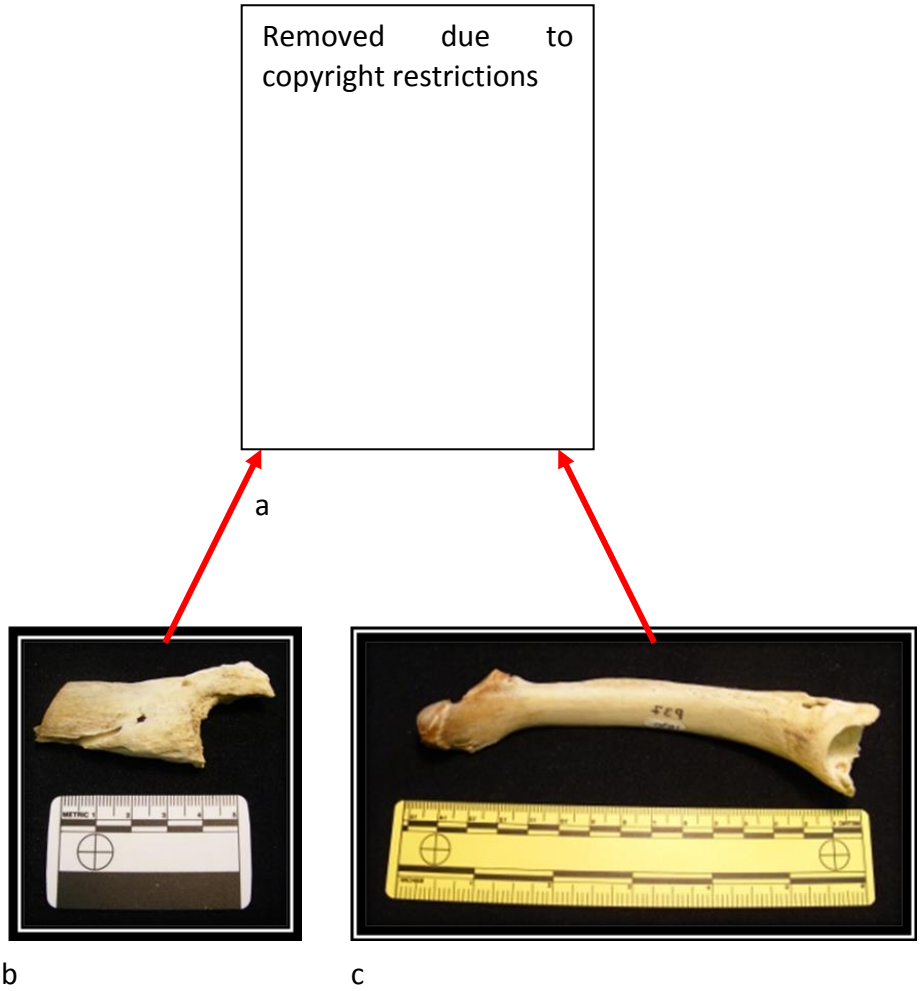


Figure 9.31 Two fragments of the same horse rib displaying a large space-occupying lesion with smooth, rounded margins (b, c). The radiograph shows a pathological fracture and a marked sclerotic response (a) (Photos: Author, X-ray: Dr. J. Buckberry).

When the two fragments are united, the extent of the cavity within the rib is evident. The interior of the rib is smooth and well- rounded, as are the margins of the cloaca (Figure 9.32).

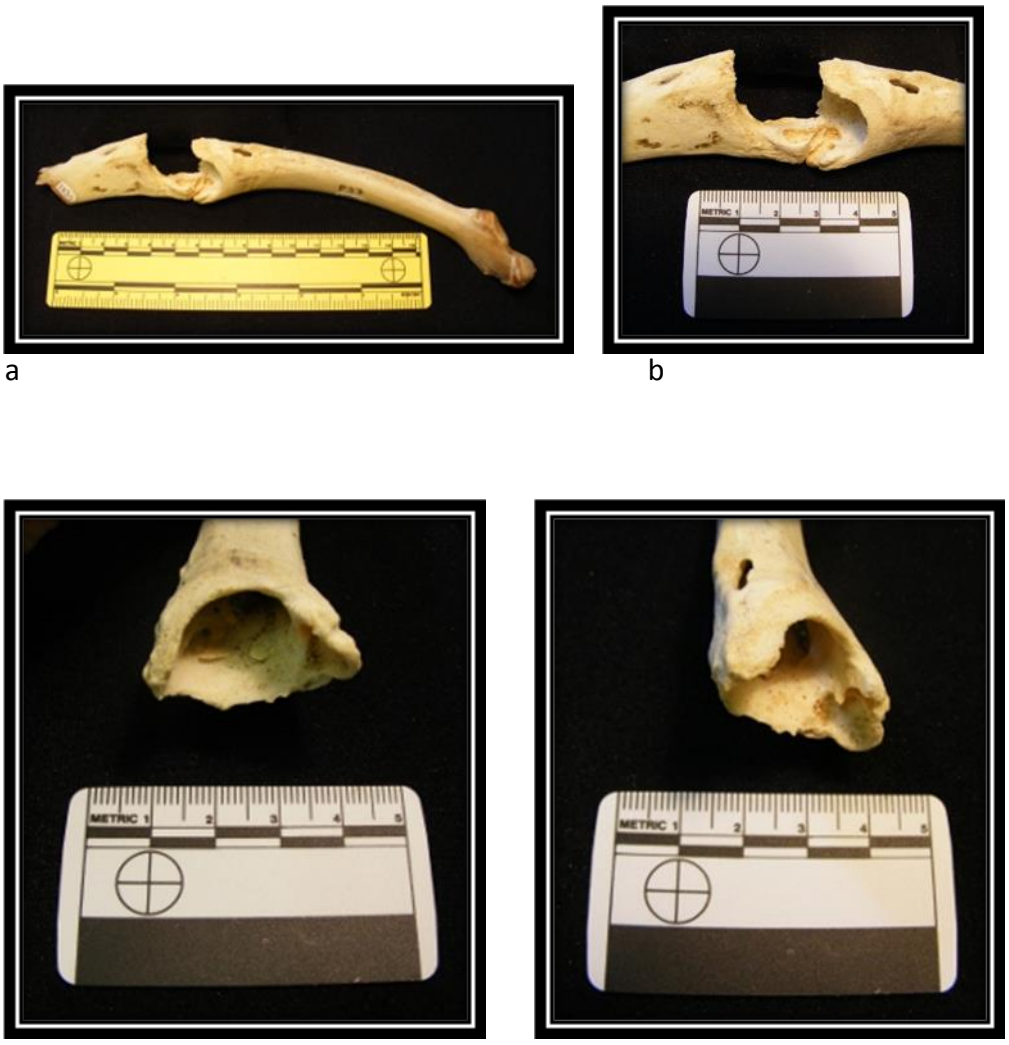


Figure 9.32 United horse rib (a), displaying large circular space-occupying lesion and a smooth, remodelled lesion interior (b). The presence of swelling and a cloaca (c, d) are indicative of an infective process and the removal of purulent exudate (Photo: Author)

Summary and differential diagnosis

It is difficult to ascertain whether this case of osteomyelitis was secondary to the fracture, or whether the fracture was associated with a loss of structural integrity because of the destruction of bone. If this was not the result of trauma, the alternatives are transfer from a soft-tissue focus or haematogenous dissemination (section 4.2.3). Pyogenic osteomyelitis could be the result of non-specific bacteria or specific bacteria such as MTB Complex. This rib, when articulated, in some ways resembles the 20th century illustration of the tuberculous cattle rib (see Figure 3.9). Although this rib does not possess a proliferation of disorganised new bone, this is not to say that some was not present, having been subsequently lost or destroyed. Despite this, the cavity within the rib is similar, and for this reason the rib was sampled for aDNA analysis.

9.5 Wetwang Slack, Nr. Wetwang, East Riding of Yorkshire

The faunal remains from Wetwang Slack were excavated from a variety of features principally associated with settlement: ditches, pits and postholes (Scott n.d). However, some of the remains were associated with human graves and a number of articulated animal burials (ABG's) (n=26) were also excavated (Scott n.d). The assemblage was recorded in the 1980s. However, the report was not published and only a summary draft completed. Unfortunately, the report contains no raw data, phasing or quantification information. In spite of these drawbacks, the assemblage was selected for three main reasons: Wetwang Slack represents the largest Iron Age zooarchaeological assemblage in northern England, the settlement site is contemporaneous with a large cemetery containing individuals with macroscopic lesions consistent with MTB complex disease (see section 3.12.5; Good 2005). The presence of ABGs also allows for the observation of lesion distribution in pathological examples. The results from the analysis of both the disarticulated assemblage (section 9.5.1) and the ABGs (section 9.5.2) are presented below.

9.5.1 The disarticulated assemblage

Due to time constraints, it was not feasible to record the disarticulated assemblage in its entirety; however, an assessment was conducted in order to establish a Total Number of Fragments (TNF) count (Table 9.5) and to provide a basic overview of species ratios (Number of Identifiable Specimens, NISP) (Table 9.6). Unfortunately, this meant that more detailed information pertaining to age-at-death, skeletal element representation and sex assessment was not available for interpretation.

With the help of Dr. John Dent (the Director of excavations between 1975 and 1981), a large proportion of the contexts recorded were broadly phased (Table 9.5). For the purposes of this research, the Iron Age and Iron Age/Romano-British phases form the focus of the following presentation, totalling more than 50% of the TNF.

Table 9.5 Total Number of Fragments (TNF) per time period at Wetwang Slack

Time Period	TNF	% TNF
Neolithic/Bronze Age	119	0.5%
Iron Age	13231	47%
Iron Age/Romano-British	2996	10.5%
Romano-British	8063	28%
Unknown (incl. Modern)	3883	14%
TOTAL	**28292**	**100%**

The assemblage totalled 28,292 fragments, of which 13,231 were dateable to the Iron Age and 2,996 to the transitional period (Iron Age/Romano-British). The Iron Age assemblage is the most abundant, representing nearly half of the total assemblage (47%). The excavations at Wetwang Slack were extensive and the site was divided into different areas, which were themselves, sub-divided (Areas 6-13). The Iron Age bones were predominantly recovered from Area 9, although all areas are represented to a greater or lesser degree. The Iron Age/Romano-British assemblage is less representative of the site as a whole, with the majority of bones recovered from Area 7.

Table 9.6 Total Number of Fragments (TNF) by area and phase

Area	IRON AGE (TNF)	IRON AGE/ROMANO-BRITISH (TNF)
6	1136	27
7	2801	2169
8	176	-
9	5259	1
10	447	-
11	2210	799
12	934	-
13	268	-
TOTAL	**13231**	**2996**

The overwhelming majority of bones from both phases (Iron Age - 80%; Iron Age/Romano-British - 69%) were unidentifiable to species. Just 20% of the Iron Age bones and 32% of the Iron Age/Romano-British bones were diagnostic enough for identification (Table 9.7). The NISP data illustrates the dominance of sheep/goat in both phases, followed by cattle and pig (Figure 9.33). In addition to the three main domesticates, horse, deer, dog and bird were also identified, but in much smaller numbers. Disarticulated human remains were found in both phases; this is unsurprising considering the presence of the large cemetery and the fact that some animal bones were recovered from human graves, where mixing could occur.

Table 9.7 Number of Identifiable Specimens (NISP) data for the Iron Age and Iron Age/Romano-British Phases at Wetwang Slack

	IRON AGE		IRON AGE/ROMANO-BRITISH	
SPECIES	**NISP**	**%NISP**	**NISP**	**%NISP**
Cattle	886	33	125	13
Sheep	4	0.1	-	-
Goat	4	0.1	-	-
Sheep/Goat	1265	47	729	77
Pig	309	12	41	4
Horse	176	7	33	3
Deer sp.	6	0.2	-	-
Dog	13	0.5	3	0.1
Bird sp.	2	0.1	1	0
Human	5	0.2	13	<0.1
TOTAL No. IDENTIFIED	**2671**		**945**	
LTM	3657		291	
MTM	6877		1759	
STM	15		1	
Other	12		-	
TOTAL No. UNIDENTIFIED	**10560**		**2051**	
TNF	**13231**		**2996**	

Key: Large Terrestrial Mammals (LTM); Medium Terrestrial Mammals (MTM); Small Terrestrial Mammals (STM)

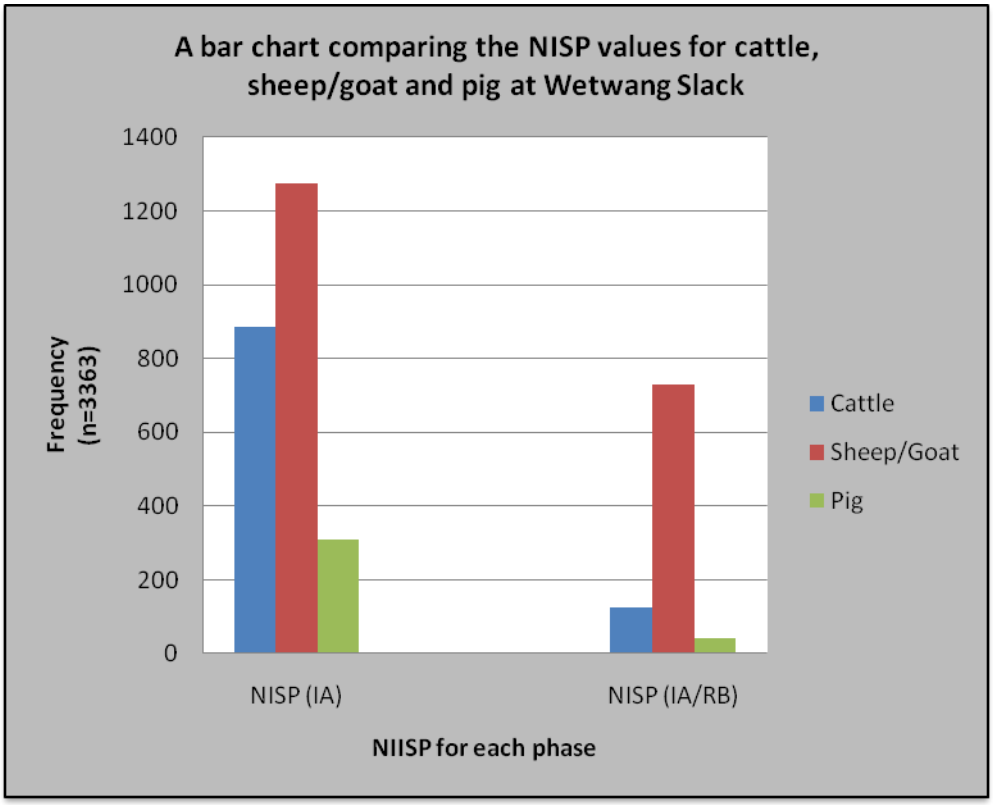


Figure 9.33 Number of Identifiable Specimen (NISP) values for cattle, sheep/goat and pig at Wetwang Slack in the Iron Age and Iron Age/Romano-British phases

9.5.2 Palaeopathology: Iron Age Phase

One hundred and forty-five types of pathology were recorded on 121 bones, equating to just 1% of the entire assemblage for this phase. Sheep/goat dominate this phase as in the Iron Age/Romano-British phase (see Table 9.7), however, pathological change was most frequently identified on cattle bones (38%). Sheep/goat closely follow (36%), with the remaining identified species forming less than 7% of the pathological bones identified when combined (Figure 9.34). The frequency of pathological cattle and sheep/goat bones was relatively equal, but

when viewed in the context of the overall NISP totals for each species, cattle appeared to display a greater overall frequency of pathological bones. However, this was not significant at α = 0.05 (X^2 = 3.48, *p* = .0621, p > 0.05, d.f. = 1, chi square test) and the H_0 was accepted (Appendix 4).

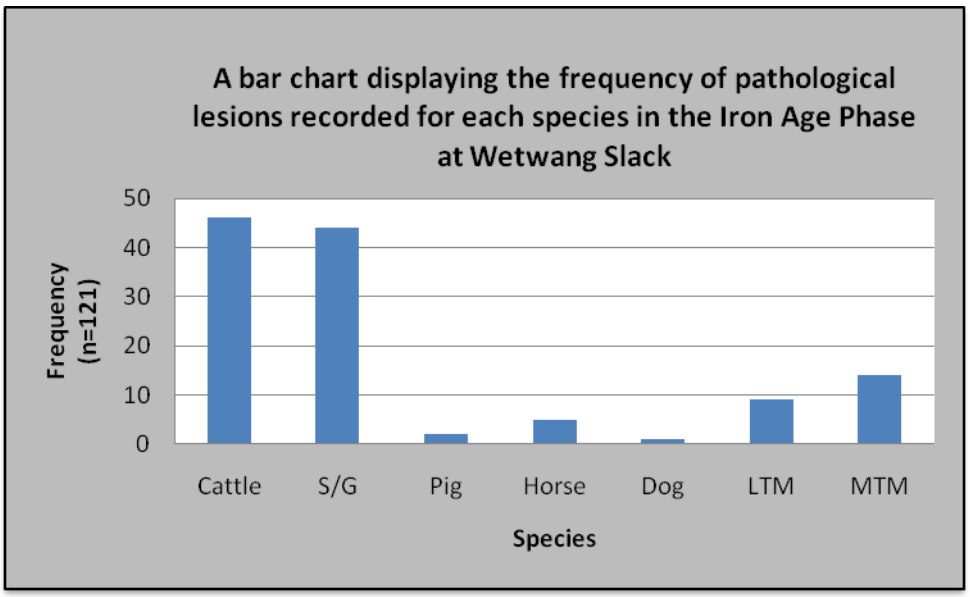


Figure 9.34 The frequency of pathological lesions by species in the Iron Age Phase at Wetwang Slack

A summary of palaeopathological lesion types

Table 9.8 and Figure 9.35 illustrate the frequency of pathological conditions by species for the Iron Age phase at Wetwang Slack. The majority of lesion types recorded fall within the 'other' category and comprise: fractures (4%), congenital (5%), abnormal attrition (20%), pulp-cavity exposure (PCE) (2%), tooth impaction (2%), ante-mortem tooth loss (2%), enlarged tooth sockets (periodontal disease) (2%), calculus (15%) and hypercementosis of tooth roots (49%). Abnormal bone proliferation (36%) and abnormal bone lysis (20%) represent the most frequent

pathology types recorded after 'other'. Periostosis (79%) is by far the most prominent bone formation type, followed by osteophyte formation (12%), enthesophyte formation (8%) and endosteal bone formation (2%). Pitting/porosity dominate the bone lysis lesion type (41%), followed by resorptive space-occupying lesions (28%) porous, lytic lesions (14%), osteochondrosis manifesta (14%) and a single example of a cleft/non-pathological cortical bone defect (3%). The remaining pathology types include four cases of abnormal bone shape: dysplasia, asymmetry and congenital malformation and a single case of abnormal bone size: an enlarged foramen. There were also four combined cases, two involving cattle femora exhibiting osteoarthrosis, including: joint contour change, eburnation and pitting/porosity; one involving a sheep/goat mandible with ventral margin disturbance of the mandible associated with perforation of the cortical bone and finally a horse metatarsal with both proliferative and lytic lesions, possibly representing a case of spavin.

Table 9.8 Iron Age Phase: Summary of pathological lesion types by species

Species Affected	Lesion Type					
	Proliferation	Lysis	Shape	Size	Combination	Other
Cattle	17	18	2	1	2	12
Sheep/Goat	15	4	1	-	1	40
Horse	2	2	-	-	1	-
Pig	2	-	-	-	-	-
Dog	-	-	-	-	-	1
LTM	5	3	1	-	-	1
MTM	11	2	-	-	-	1
TOTAL No.	**52**	**29**	**4**	**1**	**4**	**55**
TOTAL %	**36**	**20**	**3**	**1**	**3**	**38**

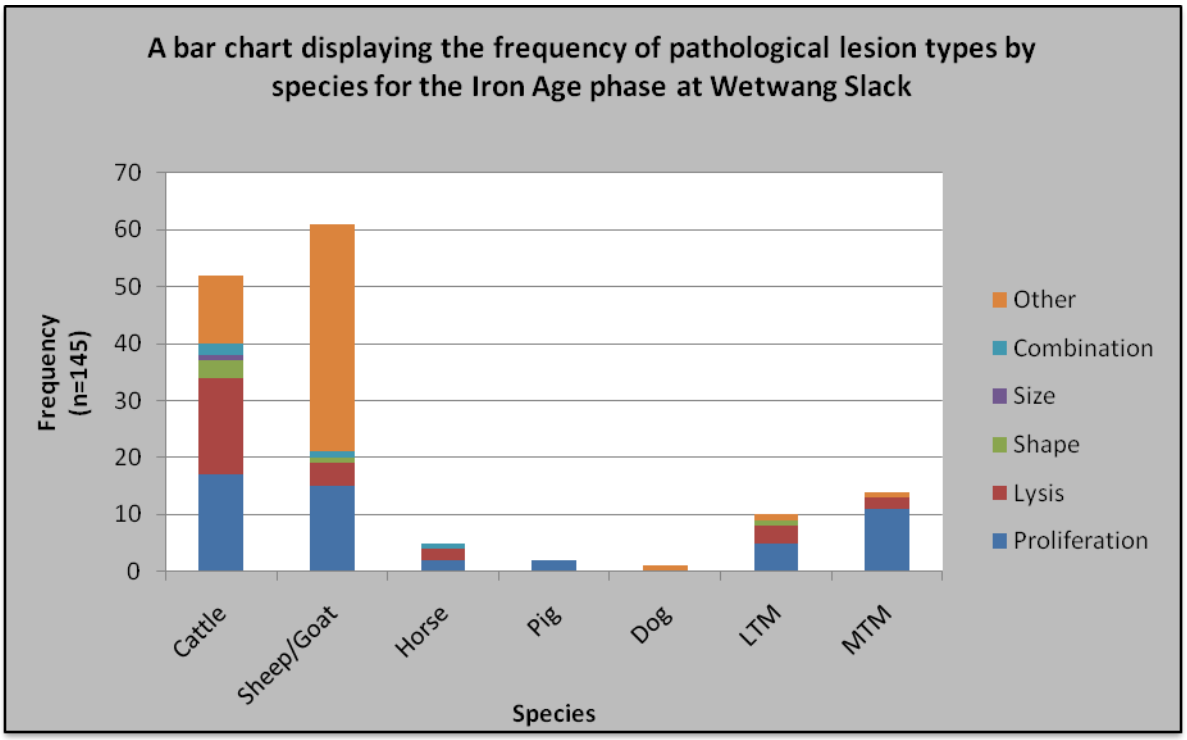


Figure 9.35 The frequency of pathological lesion types by species in the Iron Age Phase at Wetwang Slack

A summary of palaeopathological lesion characteristics: aetiologies

Figure 9.36 and Table 9.9 illustrate the frequency of pathological conditions recorded by species for the Iron Age phase at Wetwang Slack. Non-specific bone proliferation, potentially indicative of inflammation due to infection, was the most frequent category overall (32%), followed by oral pathology (27%), arthropathy (14%), non-specific bone lysis (14%), trauma (6%), congenital (3%) and other (3%).

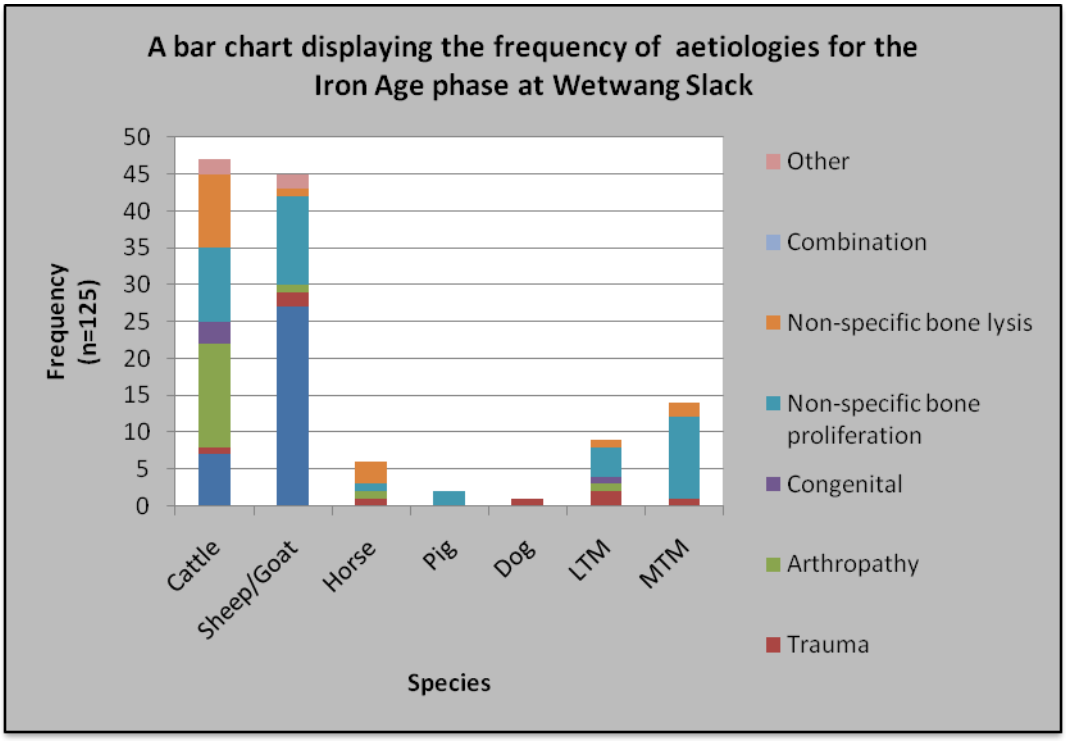


Figure 9.36 The frequency of aetiologies recorded by species for the Iron Age phase at Wetwang Slack

Table 9.9 Iron Age Phase: Summary of aetiologies by species

Species Affected	General Aetiology Categories							
	Oral	Trauma	Arthropathy	Congenital	Infection?		Mixed lesion	Other
					Non-specific bone proliferation	Non-specific bone lysis		
Cattle	7	1	15	3	10	10	-	2
Sheep/Goat	27	2	1	-	12	1	-	2
Horse	-	1	1	-	1	3	-	-
Pig	-	-	-	-	2	-	-	-
Dog	-	1	-	-	-	-	-	-
LTM	-	2	1	1	4	1	-	-
MTM	-	1	-	-	11	2	-	-
TOTAL No.	**34**	**8**	**18**	**4**	**40**	**17**	**-**	**4**
TOTAL %	**27**	**6**	**14**	**3**	**32**	**14**	**-**	**3**

With the exception of non-specific bone proliferation, oral pathology, arthropathy and non-specific bone lysis, the other aetiologies were relatively low in number. For this reason, they were excluded from statistical analyses. In addition, only cattle and sheep/goat were included in the statistical analyses because they represent the two most frequent species, allowing their pathological data to be compared and contrasted using chi-square (Appendix 4). Oral pathology and non-specific bone lysis was more frequently identified in sheep/goat compared with cattle. Both of these differences were significant at $\alpha = 0.05$ (Table 9.10). This difference was also significant when the LTM and MTM data was combined with cattle and sheep/goat for non-specific bone lysis. Arthropathy was identified more frequently in cattle, this difference was also significant at $\alpha = 0.05$. By contrast with non-specific bone lysis, there was little difference in the frequency of non-specific bone proliferation between sheep/goat and cattle. This is supported by the lack of a significant difference displayed at $\alpha = 0.05$. A comparison of the recorded observations of non-specific bone proliferation and non-specific bone lysis also produced a significant difference. There are fewer observations of non-specific bone lysis in sheep/goat by comparison to non-specific bone proliferation. This is not a result of chance and is different to the situation in cattle, where both aetiologies are observed equally.

Table 9.10 X^2 results: cattle and sheep/goat aetiologies

Aetiology (cattle vs. sheep/goat)	$X^2_{(1)}$	*P* value	H_0 Accept or reject?
Oral pathology	5.97	.0146	**Reject**
Arthropathy	14.77	.0001	**Reject**
Non-specific bone lysis	12.78	.0004	**Reject**
Non-specific bone proliferation	.18	.6721	Accept
Sheep/goat: Non-specific bone proliferation vs. non-specific bone lysis	9.36	.0022	**Reject**

Evidence for possible infection and differential diagnosis

Non-specific bone proliferation and bone lysis, when combined, comprise 46% of the lesion types recorded. Although it is impossible to determine aetiology from isolated, non-specific lesions like these, these may potentially indicate infection. Apart from a single case of endostosis (2%), the rest of the bone proliferation observed was periostosis (98%). All skeletal regions (cranial, oral, axial and appendicular) were affected. There was a statistically significant difference in the distribution of lesions throughout the skeleton at $\alpha = 0.05$ ($X^2 = 19.4$, $p = .0002$, $p < 0.05$, d.f. = 3), indicating that the lesions were not equally distributed. The data suggests that the appendicular and axial regions are favoured in the location of non-specific bone proliferation, with the former dominating the lesion locations (Figure 9.37). A statistically significant difference was identified in the distribution of lesions between these two specific regions at $\alpha = 0.05$ ($X^2 = 4.48$, $p = .0342$, $p < 0.05$, d.f. = 1). This confirms that the distribution of the lesions was not due to chance and supports the higher frequency of the appendicular skeletal region.

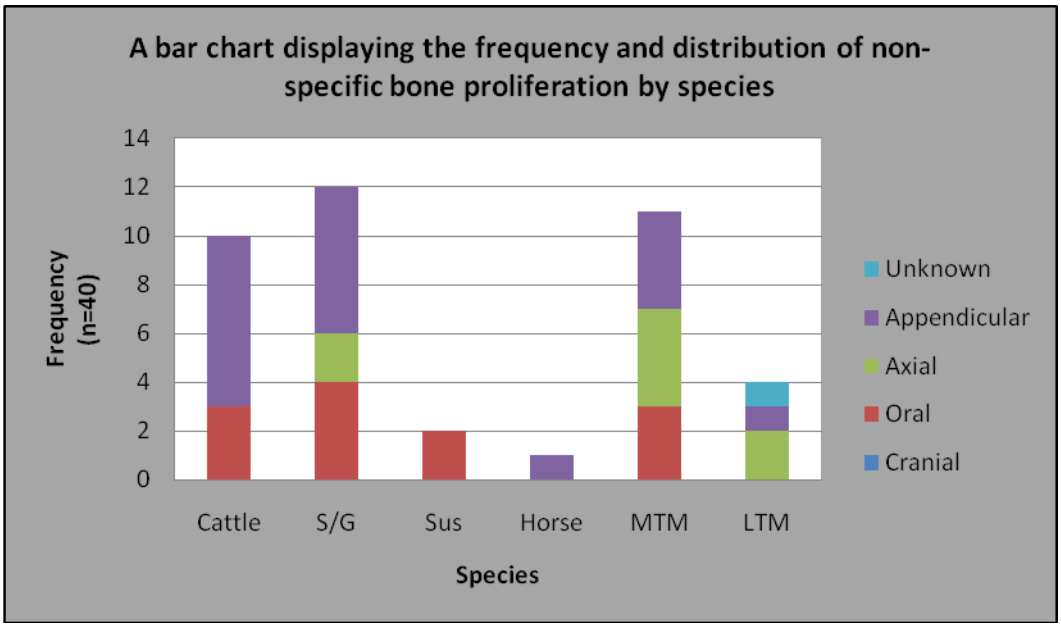


Figure 9.37 Non-specific bone proliferation by skeletal region in the Iron Age phase at Wetwang Slack

In the appendicular skeleton, periostosis comprised plaques of new woven bone predominantly located on the long bone diaphyses (Figure 9.38).

a b

Figure 9.38 Substantial plaque of compact new bone affecting a Medium Terrestrial Mammal (MTM) long bone fragment (a) with close-up of the periostosis (b) (Photo: Author)

These plaques of new bone may be the result of systemic infection, trauma, neoplasia, metabolic/nutritional deficiency or be associated with osteomyelitis. In the absence of other associated lesions or a more complete skeleton, little can be ventured as to their aetiology, apart from whether they were active, healed or healing at death. Five out of eight cases of periostosis affecting the axial skeleton were located on the ribs of sheep/goat, MTM and LTM fragments. Three of these were on the visceral surfaces and are strongly suggestive of respiratory infection (Figure 9.39). The other examples affecting the lateral surfaces of the ribs may represent either trauma or infection.

a b

Figure 9.39 Periosteal new bone formation on the visceral surface of a Medium Terrestrial Mammal (MTM) rib (a), with close up of the Periostosis (b) (Photo: Author)

Twelve cases of periostosis were recorded on the mandible (oral pathology) affecting both the buccal and lingual surfaces, along with the ascending ramus. Those lesions located in close association with the teeth may be associated with periodontal disease, infection or trauma. The lesions located on the ascending ramus may also be associated with infection and trauma.

Non-specific bone lysis comprised 14% of the pathological conditions recorded. The different types of bone loss identified included: space occupying lesions (44%), pitting/porosity (28%), porous, lytic lesions (22%) and an enlarged foramen (5%). The majority of these lesions were located in the axial skeleton (Figure 9.40). Unfortunately, there was not enough data to statistically test the distribution of the lesions in relation to all four skeletal regions. However, when the appendicular and axial skeletal regions were compared, no significant difference was identified at $\alpha = 0.05$ ($X^2 = 3.26$, $p = .0707$, $p > 0.05$, d.f. = 1).

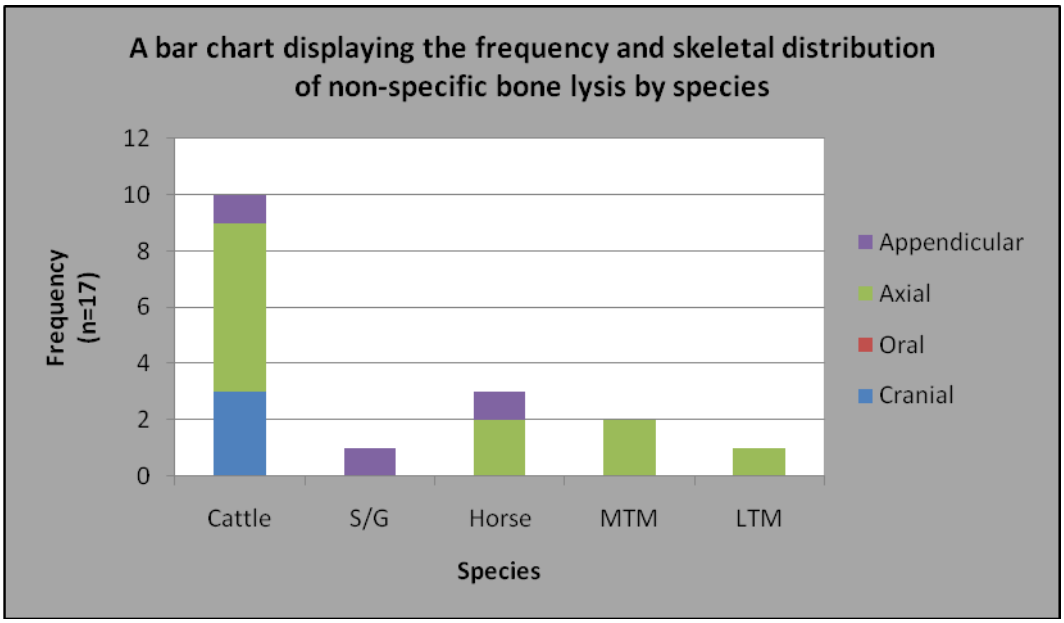


Figure 9.40 Non-specific bone lysis by skeletal region in the Iron Age phase at Wetwang Slack

Space-occupying lesions were the most frequent type of bone loss lesion identified. Eight examples were identified, these affected: a MTM thoracic spinous process and lumbar vertebra, a LTM spinous process, a cattle axis, spinous process, skull fragment and navicular cuboid and a horse astragalus. A small space-occupying lesion was observed in a cattle axis, located just beneath the dens. It was small and

circular in shape (c.3mm in diameter); it was relatively shallow and had rounded, smooth edges. This may represent a small cystic lesion or even a non-metric, non-pathological trait. A broken MTM lumbar vertebra revealed a cavity within the vertebral body associated with an enlarged foramen within the vertebral foramen. The margins of this cavity were smooth and remodelled, potentially indicating the presence of an infective focus within the cancellous bone. The potential differential diagnoses for a lesion of this type would include: pyogenic osteomyelitis, infective process (i.e. brucellosis, tuberculosis), benign neoplasm, secondary metastatic tumour and hydatid disease (echinococcosis). There was no associated new bone formation or any other pitting or porosity on any portion of the fragmented vertebra. This would rule out brucellosis, and also in the absence of a cloaca, sequestrum or new bone formation, pyogenic osteomyelitis would also seem improbable, unless the enlarged vertebral foramen was acting as a substitute cloaca for any exudate collected within the vertebral body. However, if this was the case, one would expect to observe reactive new bone formation within the vertebral foramen. Secondary metastatic tumour is a possibility, although one would expect the margins of the lesion to be less regular. As this lesion possessed remodelled margins, echinococcosis can be ruled out. This disease is not normally associated with a periosteal or sclerotic response. Therefore, this lesion could represent a benign neoplasm or a cystic lesion. If this was a space-occupying lesion associated with MTB complex, more destruction would be expected, unless the tubercle or 'cold fistulised abscess' had been contained and the infection overcome – however, without the entire element present, the extent of the lesion cannot be fully

appreciated. Another space-occupying lesion was observed on the lateral side of a MTM thoracic spinous process (Figure 9.41).

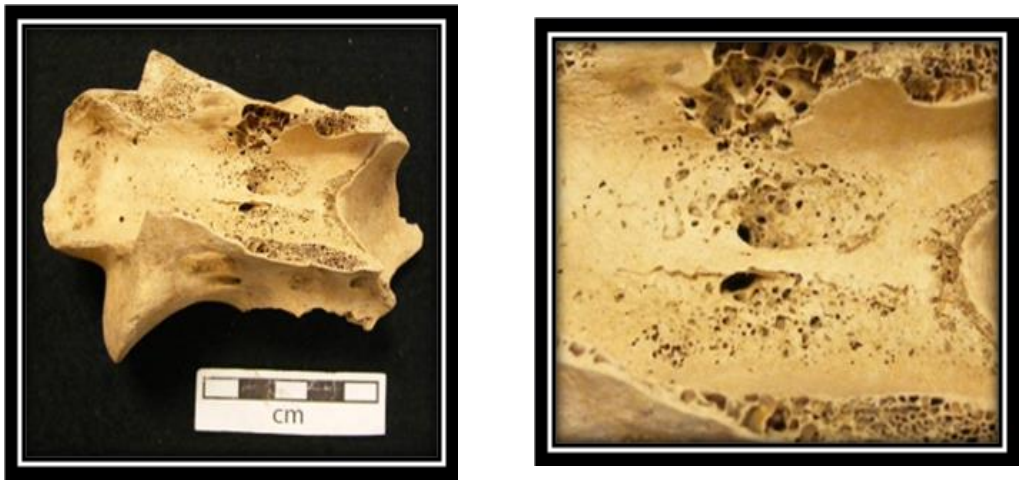
Figure 9.41 Space-occupying lesion in a MTM thoracic spinous process (a, d), with close-up of the woven bone lining the lesion (b) and the misshapen spinous process (e, f). X-ray image (taken at 60kV) displays sclerotic margin (indicated by red arrow) (c). Blue arrow indicates location of several cut-marks (Photo: Author, X-ray: J. Buckberry

This lesion is oval in shape and measures 2cm x 1cm, although the bone is fragmented, the lesion does not appear to perforate the spinous process. The lesion has extremely well remodelled margins, a sclerotic response that is clearly evident on the x-ray (Figure 9.41, view c). Some porous new woven bone formation lines the base of the lesion, although this is minimal. The caudal face of the spinous process is swollen and slightly misshapen with compact new bone formation. This lesion appears well-contained and in the process of healing. The two foramina located at the base of the caudal facing spinous process appear slightly enlarged, and there is some pitting associated with the swollen region proximal to this. This lesion was clearly chronic in nature, but well-contained and potentially resolved or at the very-least non-progressive, in this skeletal element. Interestingly, there were four cut marks present on the spinous process, which would indicate that the animal was still subject to butchering. The potential differential diagnoses for a lesion of this type would include: a chronic infective process (MTB Complex?), mycotic infection, secondary metastatic tumour and begin neoplasm. Although tuberculosis rarely affects the posterior portions of the vertebrae in humans, this rule does not appear to apply to animals. This lesion closely resembles the image of the pig thoracic vertebral column (Figure 3.13 – section 3.8.5) with a tuberculous focus in the spinous process. Therefore, this lesion may represent what Lignereux & Peters (1999: 342-3) term a 'cold fistulized abscess'. If the infective process was MTB Complex, it would appear to have been a chronic, well-contained lesion, although the absence of the rest of the skeletal element precludes the observation of similar lesions within the vertebral body as is present in the image of the pig

vertebral column. Space-occupying lesions were also observed on the cranial base of a cattle skull, in close proximity to the foramen magnum, the base of a thoracic spinous process and at the dorsal tip of a thoracic spinous process. Although both lesions were irregular in shape, they did possess smooth edges, suggesting either a chronic process or congenital malformation. There was no associated new bone formation; the lesions were purely lytic and not excessively destructive. The lesion associated with the spinous process is very similar to a lesion identified at the dorsal tip of a LTM spinous process and may possibly be associated with the attachment of the supraspinous ligament (see Roha 2005). Multiple well-rounded cavities were present in the articulating surface of a horse astragalus. This bone was extremely abraded and in poor condition so any associated pathology present on the articulated surface was not seen. These lesions may represent subchrondral cysts and actually be the result of arthropathy, but with the severity of diagenetic degradation, this cannot be ascertained. Finally, a space-occupying lesion was observed in a cattle navicular cuboid. The lesion was also rectangular in shape with smooth edges and a smooth interior. The aetiology of this lesion is unclear, there was no new bone formation associated with it. It may represent a non-pathological lesion or congenital abnormality.

Pitting and porosity was the second most frequent type of bone loss lesion identified. In cattle, the cranial and appendicular region was affected, with just a single case affecting the appendicular region in sheep/goat. These isolated cases may be related to infection, trauma or arthropathy when located within the joints. Porous, lytic lesions were observed in four vertebral fragments, three cattle and one

horse. Three vertebral bodies demonstrated loss of bone within the vertebral foramen. This could reflect an infective process, although the destruction is minimal perhaps because the infection was in its early stages. Another alternative is nutritional deficiency/metabolic disease or even osteoporosis (Figure 9.42). A porous, lytic lesion was also identified within a horse cervical vertebra (Figure 9.43). The lesion was irregular in shape with sharp edges; there was no remodelling of the lesion margins and no associated new bone formation, pointing towards a purely destructive process that started from within the spinal canal and did not perforate the outer surface. This potentially suggests disease of the spinal cord or associated blood vessels. An enlarged foramen was observed within the vertebral foramen of a juvenile cattle caudal vertebra. This enlargement could just reflect normal variation or a developmental anomaly; however, it could also represent the presence of infection associated with the blood vessels.



a b

Figure 9.42 Porous, lytic lesion in a cattle axis (a), with close-up view (b) (Photo: Author)

Figure 9.43 A porous lytic lesion in a horse cervical vertebra (Photo: Author)

Summary

One hundred and forty-five types of pathology were recorded on 121 bones, equating to just 1% of the entire assemblage for this phase. A roughly equal representation of pathological bones was identified for both sheep/goat and cattle, with no statistically significant difference apparent despite the greater overall frequency of sheep/goat. The frequency of those aetiologies most often recorded was compared between sheep/goat and cattle using chi-square. Statistically significant differences were identified in association with oral pathology and arthropathy. For those aetiologies that may represent infection, a statistically significant difference was identified between sheep/goat and cattle, with the latter displaying markedly fewer cases. By comparison, no significant difference was identified between sheep/goat and cattle for non-specific bone proliferation.

9.5.3 Palaeopathology: Iron Age/Romano-British

Sixty-four types of pathological conditions were recorded on 52 bones, equating to 2% of the entire assemblage for this phase. As the assemblage is dominated by sheep/goat, it is unsurprising that 79% (n=41) of the pathological bones recorded were sheep/goat (Figure 9.44). However, when the frequency of pathological cattle and sheep/goat were compared using chi-square against their respective NISP totals, the difference was not significant at $\alpha = 0.05$ ($X^2 = 2.27$, $p = .1319$, $p > 0.05$, d.f. = 1) and the H_0 was accepted (Appendix 4). The greater frequency of pathological sheep/goat bones is, therefore, clearly the product of a greater NISP total. The pathological results are tabulated according to pathology type and aetiology.

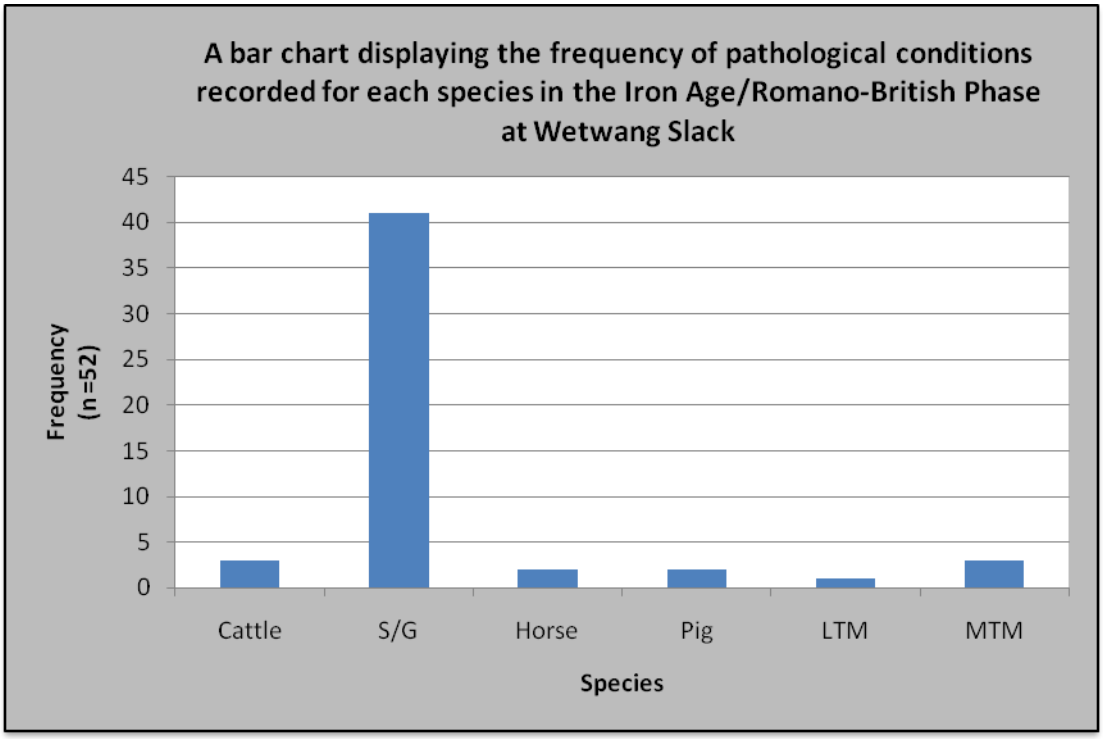


Figure 9.44 The frequency of pathological conditions by species in the Iron Age/Romano-British Phase at Wetwang Slack

A summary of palaeopathological lesion types

Table 9.11 and Figure 9.45 illustrate the frequency of pathological conditions by species for the Iron Age/Romano-British phase at Wetwang Slack. Over half (54%) of the conditions identified fall within the 'other' category and comprise: fractures (20%), congenital absence of a vertebral facet (3%), eburnation (9%), abnormal attrition (14%), dental misalignment (3%), calculus (31%) and hypercementosis of tooth roots (20%). This pattern is evident in table 8.5, where the 'oral' and 'trauma' categories are dominant. Abnormal bone proliferation (25%) and bone lysis (17%) represent the most frequent pathology lesion types recorded after 'other'. Periostosis (69%) is by far the most prominent bone formation type, followed by enthesophytes (25%) and, finally, endosteal new bone formation (6%). Lesions associated with osteochondrosis manifesta are the most frequent form of bone lysis recorded (60%), followed by porous, lytic lesions (20%), pitting/porosity (10%) and space-occupying lesion (10%). The remaining conditions include two combined cases, one involving a sheep/goat mandible with ventral margin disturbance (see Levitan 1985) of the mandible associated with new bone formation and the second involving a horse tarsal with bone loss and eburnation. A single sheep/goat premolar, visibly warped in shape, represents the single abnormal shape record.

Table 9.11 Iron Age/Romano-British Phase: Summary of pathological lesion types by species

Species Affected	Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesions	Other
Cattle	-	2	-	-	-	1
Sheep/Goat	12	9	1	-	1	31
Horse	-	-	-	-	1	1
Pig	2	-	-	-	-	-
LTM	1	-	-	-	-	-
MTM	1	-	-	-	-	2
TOTAL No.	**16**	**10**	**1**	**-**	**2**	**35**
TOTAL %	**25**	**17**	**2**	**-**	**3**	**54**

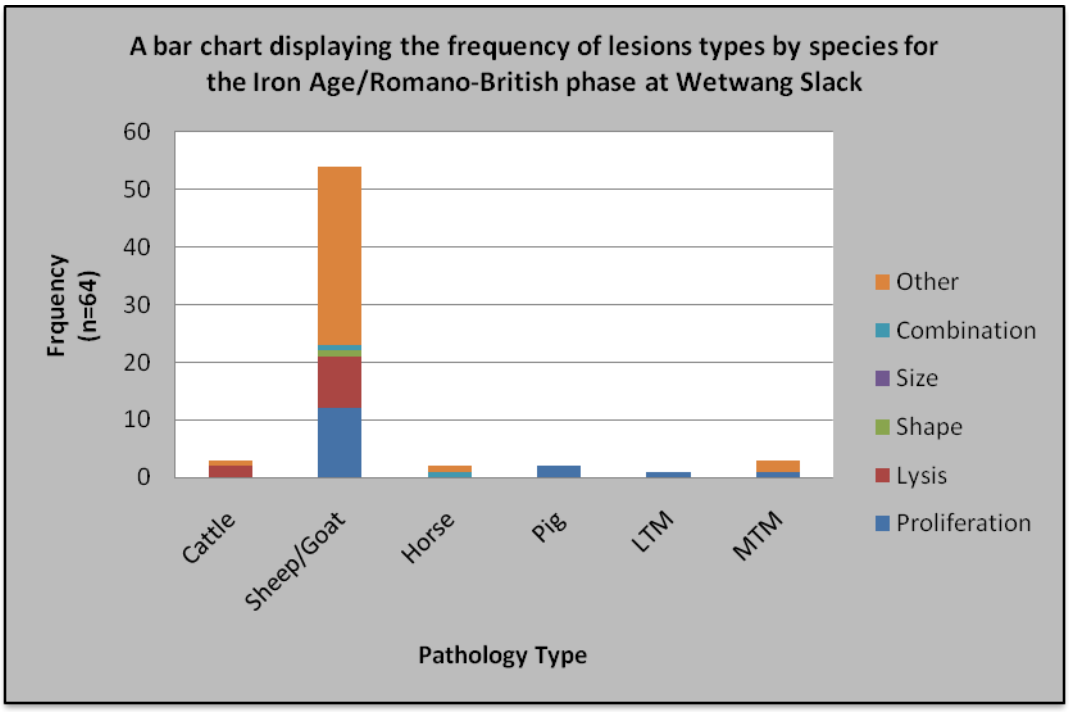


Figure 9.45 The frequency of lesion types by species in the Iron Age/Romano-British Phase at Wetwang Slack

A summary of palaeopathological lesion characteristics: aetiologies

Figure 9.46 and Table 9.12 illustrate the frequency of pathological conditions recorded by species for the Iron Age/Romano-British phase at Wetwang Slack. Those conditions associated with an oral aetiology (36%) dominate the sample. This is followed by trauma and non-specific bone proliferation (both at 19%), other (11%), arthropathy and non-specific bone lysis (both 6%) and congenital (4%).

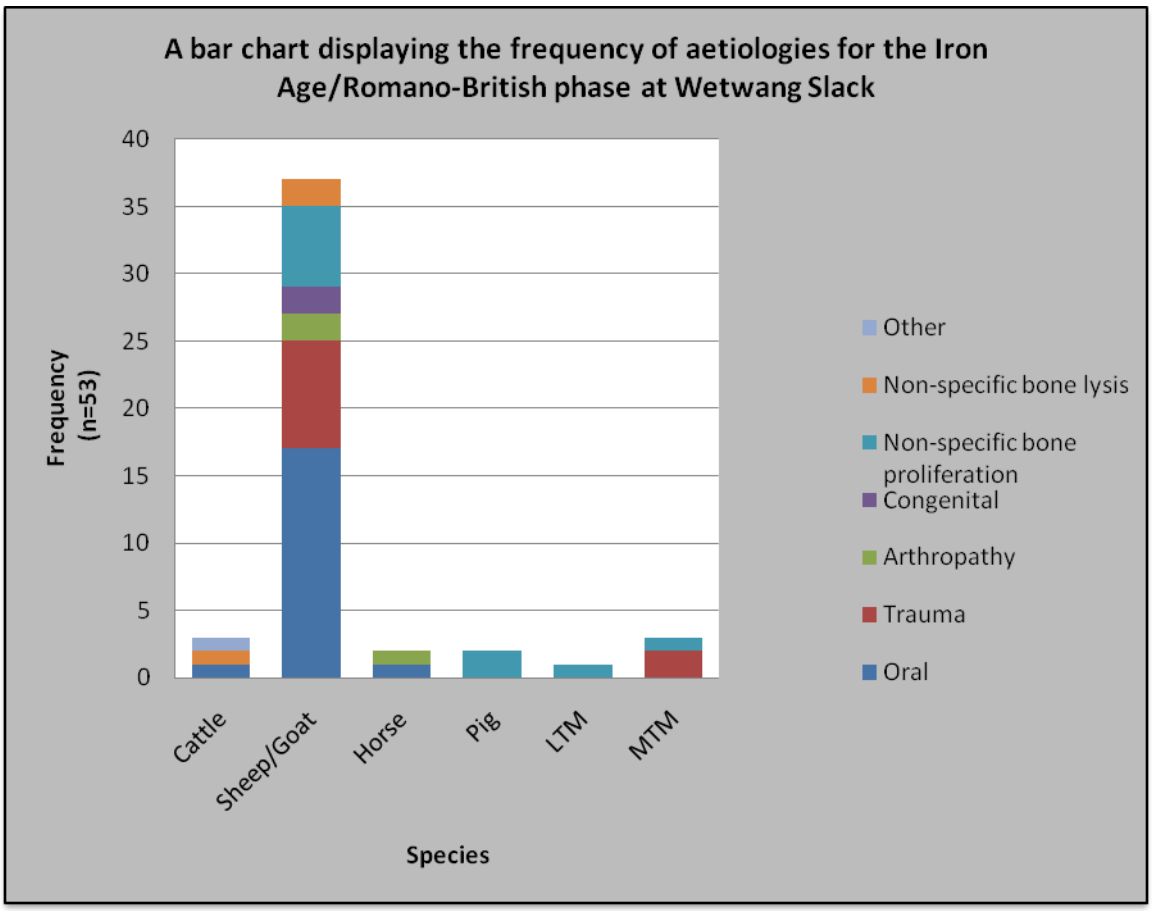


Figure 9.46 The frequency of aetiologies recorded by species in the Iron Age/Romano-British phase at Wetwang Slack

Table 9.12 Iron Age/Romano-British Phase: Summary of aetiologies by species

Species Affected	General Aetiology Categories							
	Oral	Trauma	Arthropathy	Congenital	Infection?		Mixed Lesions	Other
					Non-specific bone proliferation	Non-specific bone lysis		
Cattle	1	-	-	-	-	1	-	1
Sheep/Goat	17	8	2	2	6	2	-	5
Horse	1	-	1	-	-	-	-	-
Pig	-	-	-	-	2	-	-	-
LTM	-	-	-	-	1	-	-	-
MTM	-	2	-	-	1	-	-	-
TOTAL No.	**19**	**10**	**3**	**2**	**10**	**3**	**-**	**6**
TOTAL %	**36**	**19**	**6**	**4**	**19**	**6**	**-**	**11**

The higher frequency of sheep/goat means that this is the only species in the Iron Age/Romano-British phase at Wetwang Slack with enough data to conduct meaningful statistical analyses. Therefore, to gain insight into any potential differences between the pathological conditions associated with sheep/goat in the Iron Age and the later transition phase at Wetwang Slack, the aetiologies for both phases were compared and contrasted using chi-square (Table 9.13, Appendix 4).

Table 9.13 X^2 results: Sheep/goat aetiologies in the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

Aetiology (IA sheep/goats vs. IA-RB sheep/goat)	$X^2_{(1)}$	***P* value**	**H_0 Accept or reject?**
Oral pathology	.10	.7567	Accept
Trauma	8.25	.0041	**Reject**
Arthropathy	1.19	.2758	Accept
Non-specific bone lysis	1.19	.2758	Accept
Non-specific bone proliferation	.07	.7850	Accept
Sheep/goat: Non-specific bone proliferation vs. non-specific bone lysis	2.01	.1562	Accept
Other (osteochondrosis manifesta)	3.72	.0538	Accept

Apart from trauma, there was no statistically significant difference between the aetiologies associated with sheep/goat in the Iron Age and Iron Age/Romano-British phases at Wetwang Slack. There was also no statistically significant intra-species

difference for sheep/goat in relation to non-specific bone proliferation and non-specific bone lysis. The majority of the trauma identified in sheep/goat from the later phase was associated with rib fractures, seemingly indicating a greater frequency of trauma in the later phase. However, it is important to note that the affected ribs may have belonged to the same animal, so this difference may not be representative. The 'other' aetiology category comprised osteochondrosis manifesta (OCM) lesions. The result was not statistically significant, but only by a very small margin. This data, although very limited, could potentially indicate a greater frequency of OCM in the later phase at Wetwang Slack. Although the aetiology of this condition is not fully understood, several interesting interpretations could be ventured in the presence of more data, including, for example, the introduction of a more intense animal husbandry regime, with increased/quicker weight gain in sheep/goat.

Evidence for possible infection and differential diagnosis

Non-specific bone proliferation and bone lysis, when combined, comprise 25% of the lesion types recorded. Although it is impossible to determine aetiology from isolated, non-specific lesions like these, there are some that may potentially indicate infection. A single case of endostosis (representing 10%) was identified in a LTM long bone fragment (Figure 9.47). It possessed compact but pitted endosteal new bone formation within the medullary cavity. This may be the result of a resolved osteomyelitis, either associated with a systemic infection or localised trauma. Periostosis comprised the rest of the new bone proliferation identifications (90%). These were located in the appendicular, axial and oral regions of sheep/goat,

pig and MTM (Figure 9.48). Unfortunately, there was not enough data to conduct a chi-square 'goodness of fit' test.

a b

Figure 9.47 LTM Long bone fragment with compact endosteal new bone formation (a). Close up view of endosteal new bone (b) (Photo: Author)

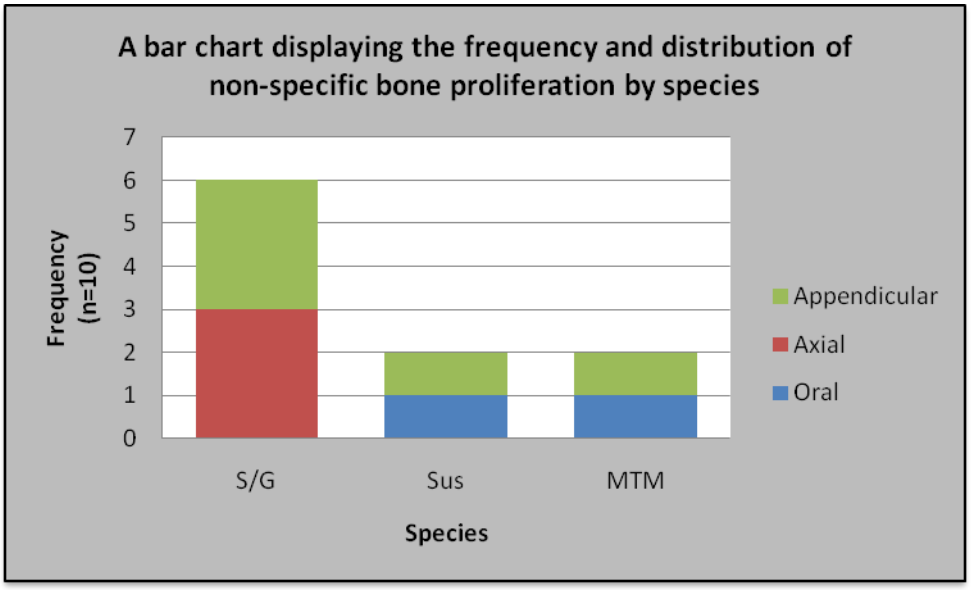
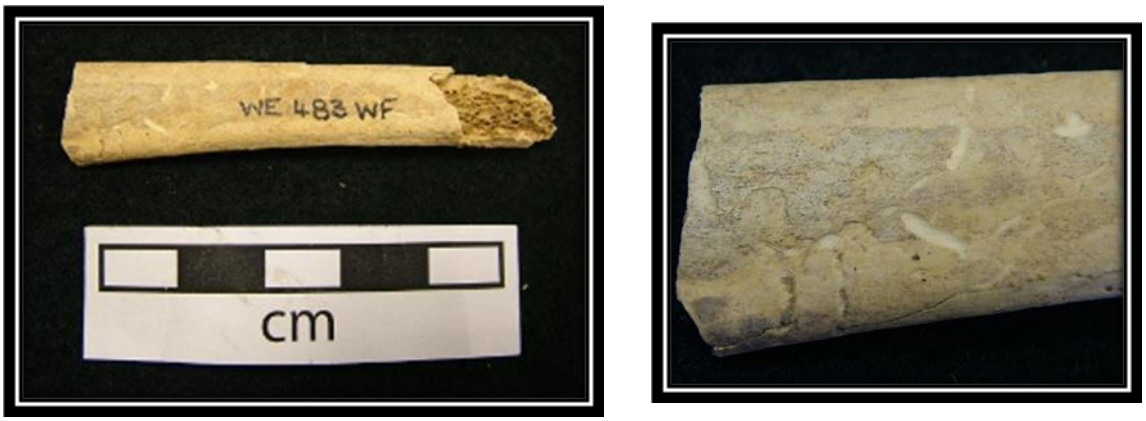


Figure 9.48 Non-specific bone proliferation by skeletal region in the Iron Age/Romano-British phase at Wetwang Slack

There are three examples of periosteal new bone formation affecting sheep/goat ribs (both the visceral and lateral surfaces) (Figure 9.49). These plaques of new bone may represent trauma or infection, with lesions affecting the visceral surface of the ribs strongly suggestive of a respiratory infection.

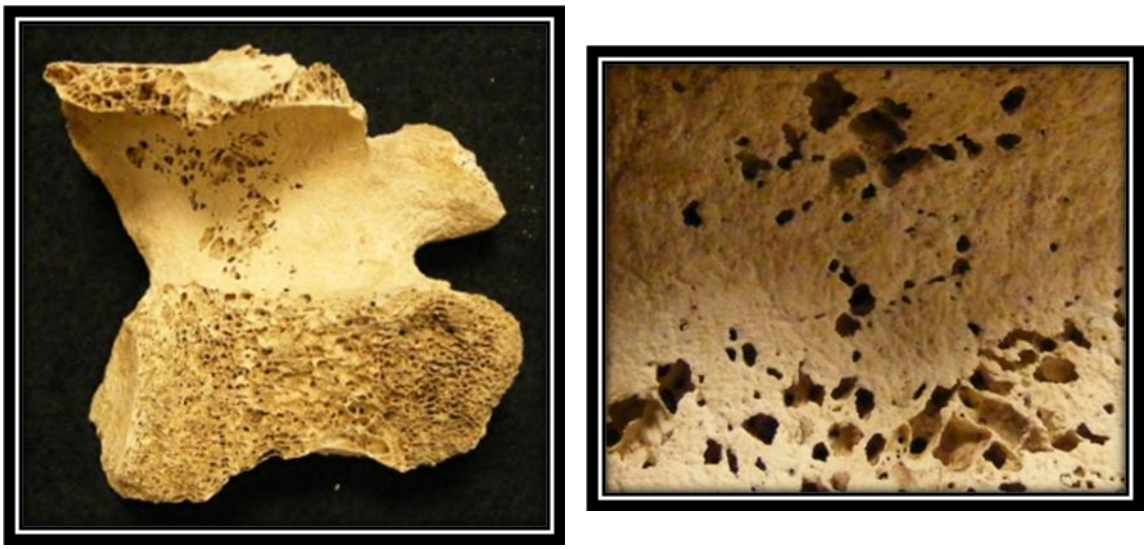


a b

Figure 9.49 Sheep/Goat rib fragment (a) with periosteal woven bone formation possibly indicating the presence of an active respiratory infection at death (b) (Photo: Author)

New woven bone proliferation was also recorded on a pig mandible, a medium terrestrial mammal (MTM) mandible fragment and a number of long bone fragments, including: a juvenile sheep/goat metatarsal shaft, a sheep/goat femur shaft, a sheep/goat tibia shaft and a pig long bone shaft. There were no obvious signs of osteomyelitis in any of the pathological long bones, but the entire skeletal element was not present. Other differential diagnoses for widespread deposition of new bone would include trauma, neoplasia, metabolic/nutritional deficiency and systemic infection.

Non-specific bone lysis was recorded in three bones. A small space-occupying lesion was identified in a heavily eroded and carnivore gnawed sheep/goat metacarpal. The circular lesion measuring 0.5cm in diameter was located on the proximal caudal shaft, just distal to the proximal epiphysis. The margins of the lesions were smooth as was the interior. There was no associated reactive new bone, but surface abrasion may have removed evidence of this process. A cattle cervical vertebra displayed evidence of a porous, lytic lesion exposing the underlying trabecular bone (Figure 9.50). The bone was very light in weight but this could be the result of taphonomic processes. Osteoporosis and nutritional deficiency are amongst the differential diagnoses, in addition to infection.



a b

Figure 9.50 Cattle cervical vertebra displaying porous, lytic lesion (a). Close-up displaying underlying trabecular bone (b) (Photo: Author)

Finally, a sheep/goat metacarpal displayed some pitting of the central area between the medial and lateral facets on the proximal articular surface. In addition to this, there was some cortical bone loss affecting both facets resembling osteochondrosis manifesta (Figure 9.51). However, osteochondrosis in sheep/goat and cattle is most often observed on the medial facet in metacarpals. Therefore, the pitting and loss of cortical bone could be related conditions, possibly an arthropathy or, alternatively, they could be separate, with the latter either a slight deviation from the normal morphology and location of osteochondrosis manifesta, a congenital/developmental defect, or even a shallow and space-occupying lesion, possibly suggestive of an early stage localised infectious arthropathy. However, a lesion associated with the latter would be far more destructive than this.

Figure 9.51 Sheep/Goat metacarpal displaying pitting at the centre of the proximal articular surface, in addition to an area of bone loss (possibly osteochondrosis manifesta) affecting both medial and lateral facets (Photo: Author)

Summary

Sixty-four types of pathology were observed on 52 bones, equating to 2% of the entire assemblage for the Iron Age/Romano-British phase at Wetwang Slack. The assemblage was dominated by sheep/goat, and unsurprisingly sheep/goat possessed the greatest number of pathological conditions. However, when this frequency was compared with the cattle data against the overall NISP counts, the actual difference between sheep/goat and cattle was found to be insignificant at $\alpha = 0.05$; the higher frequency of sheep/goat pathological bones appeared to be a product of a large sheep/goat NISP count. The aetiology data for sheep/goat was compared to the data from the Iron Age phase in an attempt to highlight any differences between the pathological conditions recorded for sheep/goat in both phases. The only statistically significant difference was associated with a greater frequency of trauma in the later phase. The rest of the aetiologies appear to be consistent for sheep/goat over this period of time at Wetwang Slack. Non-specific bone proliferation was identified in all skeletal regions. A significant difference was identified $\alpha = 0.05$ in the distribution of the lesions, with further tests focused on the appendicular and axial regions, supporting the fact that the appendicular region was favoured in the Iron Age phase at Wetwang Slack. However, when the axial and appendicular regions were statistically tested in relation to non-specific bone lysis, there was no significant difference in lesion distribution identified. Unfortunately, there was not enough data to conduct similar analyses on the Iron Age/Romano-British phase.

9.5.4 The Associated Bone Groups (ABGs)

Twenty-nine ABGs were recorded from Wetwang Slack. This number was reduced to twenty-six when it was discovered that two burials were potentially modern and one was associated with the neighbouring site of Garton Slack. Of those remaining ABGs analysed, 77% (n=20) were found to be pathological in some way. The ABGs post-date the Iron Age square barrow cemetery, dating to the later Iron Age/Early Romano-British period (Scott n.d). In her unpublished faunal report, Scott included an illustration depicting the locations of twenty-one of these ABGs. This is re-created in Figure 9.52 and shows that the majority were clustered in and around the central enclosure of the ladder settlement, which originated in the late Iron Age (Dent pers. comm.). The location of the other five ABG's in relation to the settlement features is not known.

Age-at-death and, where possible, sex was determined for each ABG recorded; this information is presented below. With the exception of the horse ABGs, the greater majority of the cattle, sheep/goat and pig were juvenile or neonate. The following sections present the results for each species with an emphasis placed upon those pathological examples sampled for aDNA analysis.

Figure 9.52 Distribution of twenty-one ABGs at Wetwang Slack (Adapted from Dent n.d: figs 9.1 & 12.1 and Scott n.d: fig 1, with additions)

Cattle ABGs

A total of eleven cattle ABGs were recorded (Table 9.14). The vast majority of these were juvenile, with just three older individuals represented; the oldest, a female, aged between 3-4 years at death. The locations of these ABGs in relation to the settlement features at Wetwang Slack are indicated in Figure 9.53. Seven ABGs were located within the boundaries of the ladder enclosure. Two were located close to the western settlement boundary, one just to the east of the ladder enclosure and another positioned to the north of the enclosure.

Table 9.14 Cattle ABGs: Age at death and sex determination

Context Number	Age Estimation in months (epiphyseal fusion & tooth eruption)	Tooth Wear (mandible wear score)	Sex Determination	Pathological?
WE 8 AQ	(36-42) – (42-48)	44	F	Y
WE 81 BG	36-42	41	M?	Y
WE 726 ADD	24-26	-	-	N
WE 300 MS	<12-18	-	-	Y
WA 55 CA	<7-10	-	-	Y
WE 595 ACC	<7-10	-	-	N
WE 304 NY	<7-10	-	-	Y
WE 742 ADE	5-6	-	-	Y
WE 166 DG	<5-6	-	-	Y
WE 494 VJ	<5-6	-	-	Y
WW 292 KR	<5-6	-	-	Y

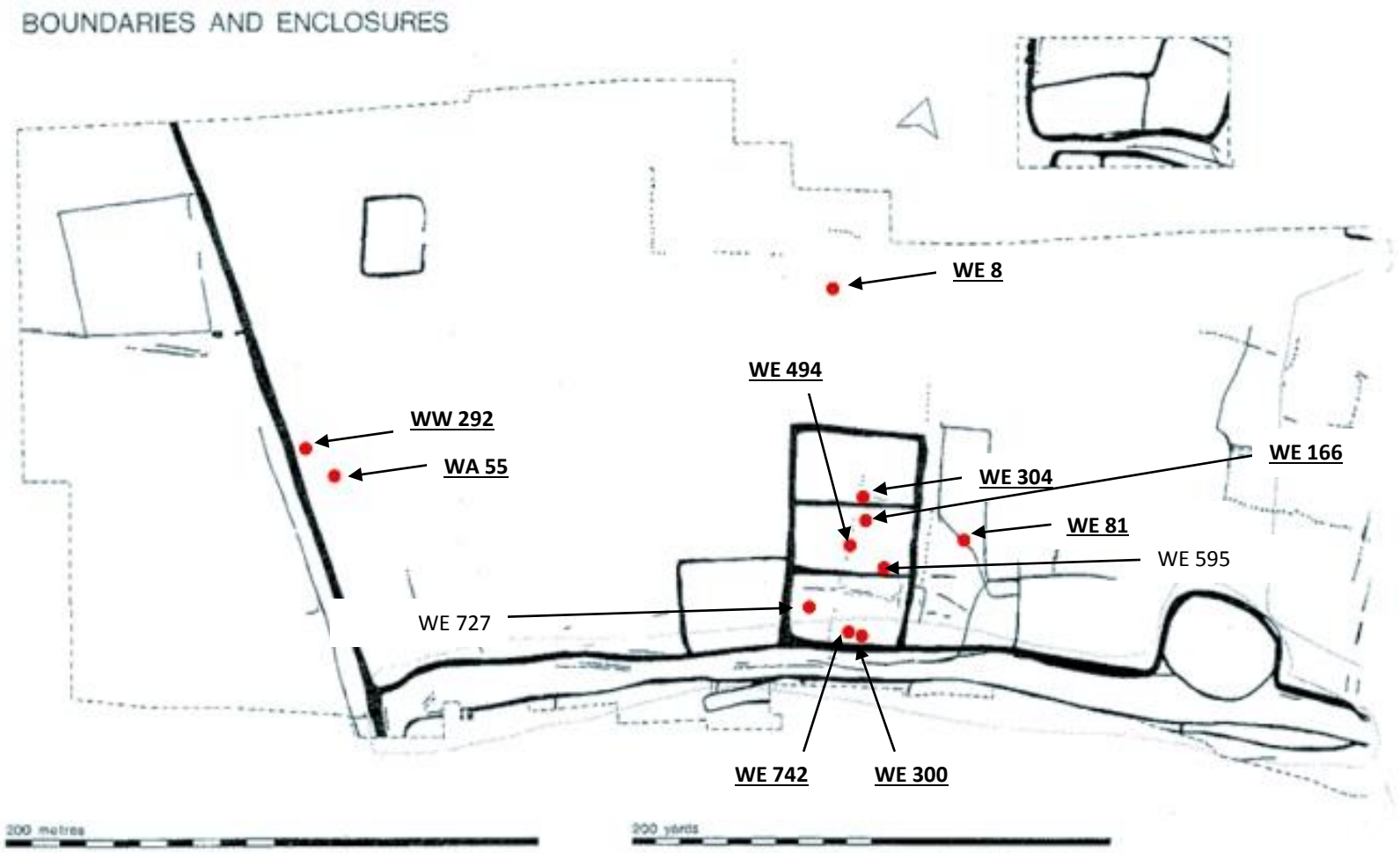


Figure 9.53 Distribution of cattle ABGs with context labels at Wetwang Slack. The pathological ABGs are bold and underlined. (Adapted from Dent n.d: figs 9.1 & 12.1 and Scott n.d: fig 1, with additions)

Palaeopathology

Nine of the eleven cattle ABGs (82%) were pathological (Table 9.15); two of these were sampled for aDNA analysis (section 9.7) and are presented in detail below. The others are briefly summarised. The different types of lesion identified and their distribution across the skeletons are presented in Figures 9.54 & 9.55. There was a significant difference in the skeletal distribution of pathological lesions throughout the skeleton at $\alpha = 0.05$ ($X^2 = 43.25$, $p = .0000$, $p < 0.05$, d.f. = 3). This indicates that the distribution is unlikely to be due to chance.

Table 9.15 Frequency of lesion types recorded for each ABG

Cattle	Frequency of Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
WE 8 AQ*	7	5	1	3	-	1
WE 81 BG*	18	3	1	3	2	5
WA 55 CA	2	4	-	1	-	-
WE 300 MS	3	1	-	-	-	-
WE 304 NY	6	-	-	-	-	-
WE 742 ADE	1	-	-	-	-	-
WE 166 DG	1	-	-	-	-	-
WE 494 VJ	4	-	-	-	-	-
WW 292 KR	2	-	-	-	-	-

*Sampled for aDNA analysis

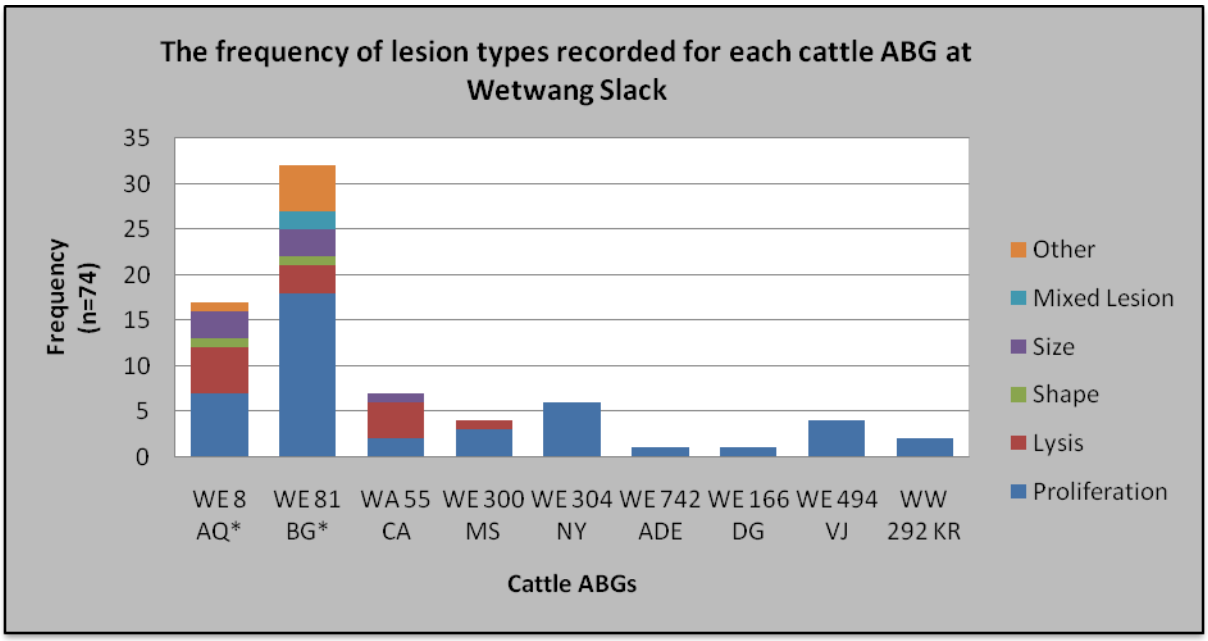


Figure 9.54 Cattle ABGs: The frequency of lesion types
*ABGs sampled for aDNA

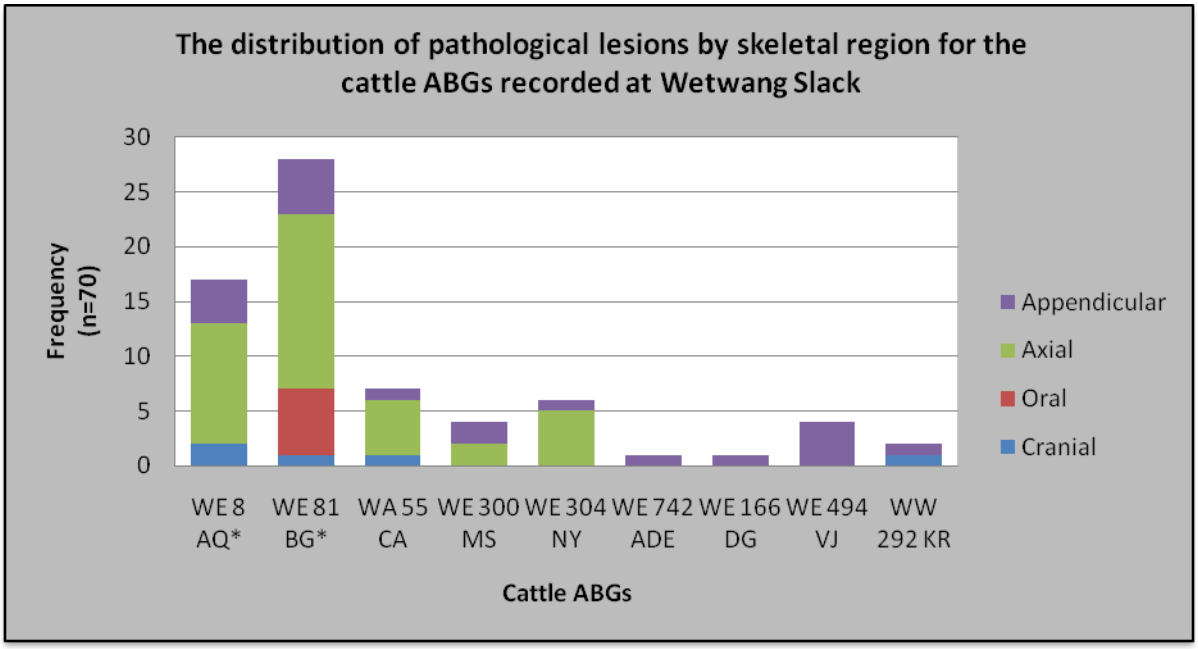


Figure 9.55 Cattle ABGs: The distribution of lesions by skeletal region
*ABGs sampled for aDNA

WE 8 AQ

This female cattle skeleton was approximately 3-4 years at death. The skeleton was located in a seemingly isolated position some distance to the north of the settlement area, away from the ladder enclosure and from any surrounding ABGs. The skeleton was complete, fully articulated and in fair-good condition (Figure 9.56).

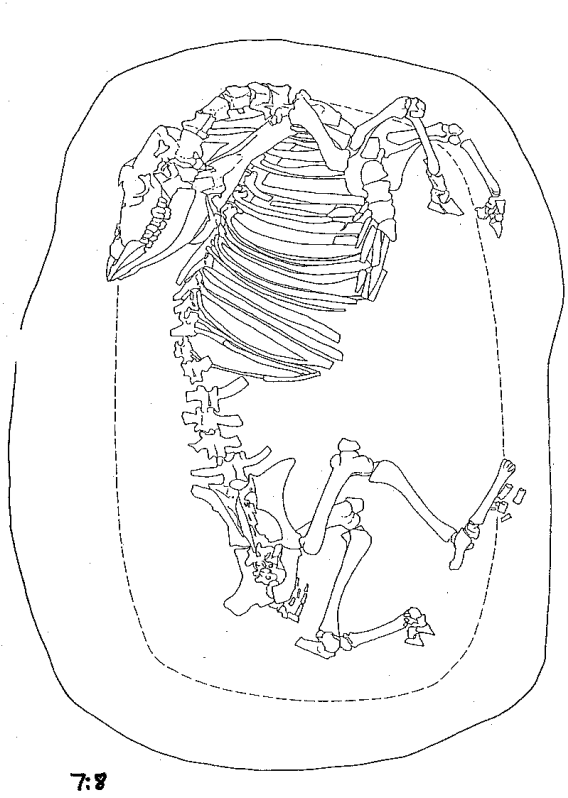


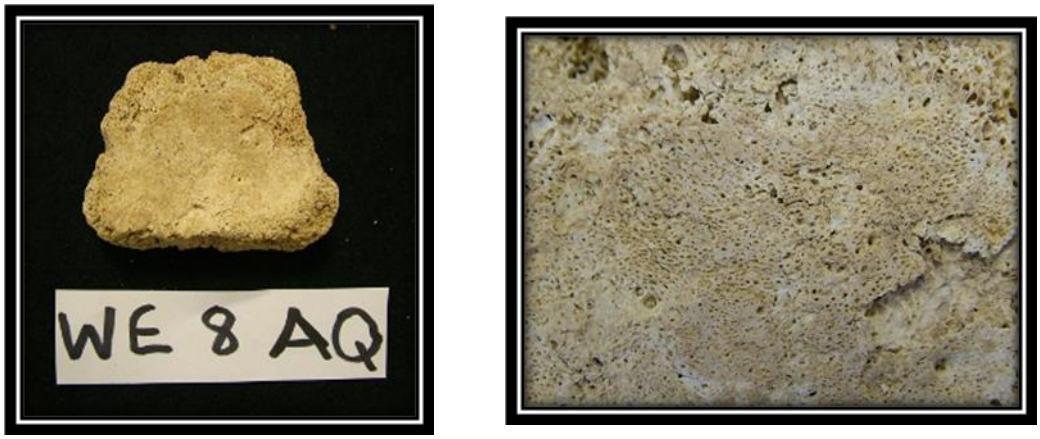
Figure 9.56 A plan of WE 8 AQ *in situ* (Dent n.d: fig 9.2)

There were seventeen instances of pathology recorded for WE 8 AQ; over half of these (65%) were located in the axial skeleton and comprised both proliferative and lytic lesions, all of which were associated with non-specific bone formation and loss. The proliferative lesions included periostosis on the visceral and lateral surfaces of

two rib fragments, and a small localised area on the ilium. New bone formation was also recorded within the vertebral foramen of a cervical vertebra (Figure 9.57) and on the ventral side of a sternal segment (Figure 9.58). The other two cases of bone proliferation were traumatic in origin and consisted of symmetrical enthesophytes on both the tibia proximal epiphyses.

a b

Figure 9.57 Cattle cervical vertebra (a) displaying passive hyperaemia with new bone formation within the vertebral foramen (b) (Photo: Author)



a b

Figure 9.58 Cattle sternum (a) with new bone formation on the ventral surface (b) (Photo: Author)

Loss of bone was recorded in five cases (29%) and consisted of a space occupying lesion affecting a tarsal, and two cases of porous, lytic lesions within the vertebral foramen of a sacral and cervical vertebra (Figure 9.59). The other two cases of bone lysis are associated with arthropathy; both temporomandibular joints were pitted.

a b

Figure 9.59 Porous, lytic lesion exposing the trabecular bone within the vertebral foramen of a cervical vertebra (Photo: Author)

Three examples of enlarged foramina were recorded for this ABG, two in lumbar vertebra (Figure 9.60) and another in a caudal vertebra. A possible congenital abnormality was identified in a metatarsal; the proximal foramen located on the cranial side of the bone was absent and the distal foramen was much smaller on the distal cranial shaft and seemingly ossified on the distal caudal shaft. This was in contrast to the other metatarsal, which possessed normal foramina. Lastly, a caudal vertebra was dysplastic, potentially representing a well-healed fracture.

a

b

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c

Figure 9.60 Enlarged foramen in a lumbar vertebra (a). The edges of this foramen are remodelled and smooth (b). The radiograph clearly depicts that the margins are sclerotic (see arrow) (c) (x-ray taken at 45kV, 2 second exposure) (Photo: Author, Radiograph: Dr. J. Buckberry)

Summary and Differential Diagnosis

The new bone proliferation on the visceral surface of the rib fragments indicates the presence of a respiratory infection; those located on the lateral sides may be as a result of infection or trauma. The bone formation within the spinal canal

suggests passive hyperaemia and suggests inflammation within the vertebral foramen, possibly associated with disease of the spinal cord and/or blood vessels or infection. The incidences of porous, lytic lesions within the vertebral foramen of the cervical and sacral vertebra may reflect a generalised osteoporotic response or be related to a nutritional deficiency or metabolic cause. However, infection again is also a possibility, specifically in light of the bone formation present within the vertebral foramen of another cervical vertebra. The presence of new bone proliferation on the ventral surface of a sternal fragment probably represents transfer either from a soft tissue focus or a ruptured lymph node. For example, reticulitis can directly transfer to the nearby sternal bones and can be a symptom of actinomycosis (section 4.4.2), although the characteristic 'lumpy jaw' appearance of the mandible was lacking in this case. Enlarged foramina have been reported upon previously in other cases of bone pathology, (see Roha 2005), however, their aetiology remains uncertain. Examples recorded both in this ABG and others during the course of this research varied in size, leading to the possibility that some may just represent normal variation. However, the example illustrated in Figure 9.60 is a more extreme case, with a definite sclerotic response visible indicating a chronic process. Therefore, the more extreme examples could represent disease of the spinal cord and/or blood vessels, inflammation of the posterior longitudinal ligament or even represent substitute cloacae - forming a convenient outlet for purulent exudate within the vertebral foramen. The sclerosis suggests that the foramen may have formed a channel (a draining cloaca), and the combination of both the bone resorption

and bone proliferation within the vertebral column along with the rib lesions may support the presence of infection. Overall, there are several suspected aetiologies associated with the pathological lesions recorded in this ABG: arthropathy, trauma and possible infection.

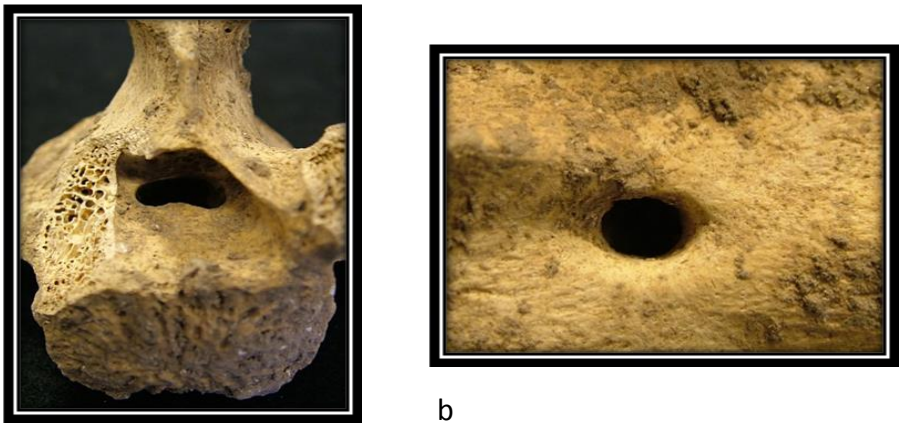
WE 81 BG

This cattle skeleton, a possible male, was aged 3-3.5 years at death and possessed the highest frequency of pathologically altered bones (n=32 lesions). The skeleton was located to the east of the ladder enclosure, close to a ditch. Lesions associated with new bone proliferation dominated the identifications, representing 56% of the pathological lesions recorded. As with WE 8 AQ, the greater majority of lesions affected the axial skeleton (57%). Periostosis was present on ten vertebrae (five thoracic and five lumbar) and on the visceral surfaces of four ribs (Figure 9.61) The plaques of new bone were predominantly located on the lateral sides of the vertebral bodies and in some cases consisted of a characteristic stain denoting the presence of a plaque of new bone, which had been subsequently removed, presumably through washing/handling. Where the plaques were present, they were fine and pitted in appearance. Two of the affected thoracic vertebrae also possessed enlarged foramina as did a caudal vertebra (Figure 9.62), whilst an affected lumbar vertebra displayed non-union of a fracture of the spinous process (Figure 9.63). The spinous process had been completely severed but callus formation indicates that the two fragments were attempting to heal albeit in a lateral displaced position. Dysplasia was noted in a

possible neighbouring lumbar spinous process, possibly related to the fracture or suggesting work-related strain and torsion to the lower region of the back. The periostosis affecting the ribs was woven and located on the visceral surfaces. Other localised areas of periostosis were also observed on the ascending ramus of each mandible, just distal to the lateral tuberosity of the humerus and on a cranial fragment. Bone lysis was recorded on a distal tibial epiphysis, proximal metatarsal epiphysis and an ilium. The latter was a small circular space-occupying lesion measuring c.3mm x 2mm, possibly representing a small cyst. Porosity/pitting that were judged to be more excessive than normal was noted in both the tibia and metatarsal epiphyses. The other lesions recorded consisted of hypercementosis affecting the roots of four teeth, probably associated with periodontal disease and arthropathy affecting both the first and second phalanges.

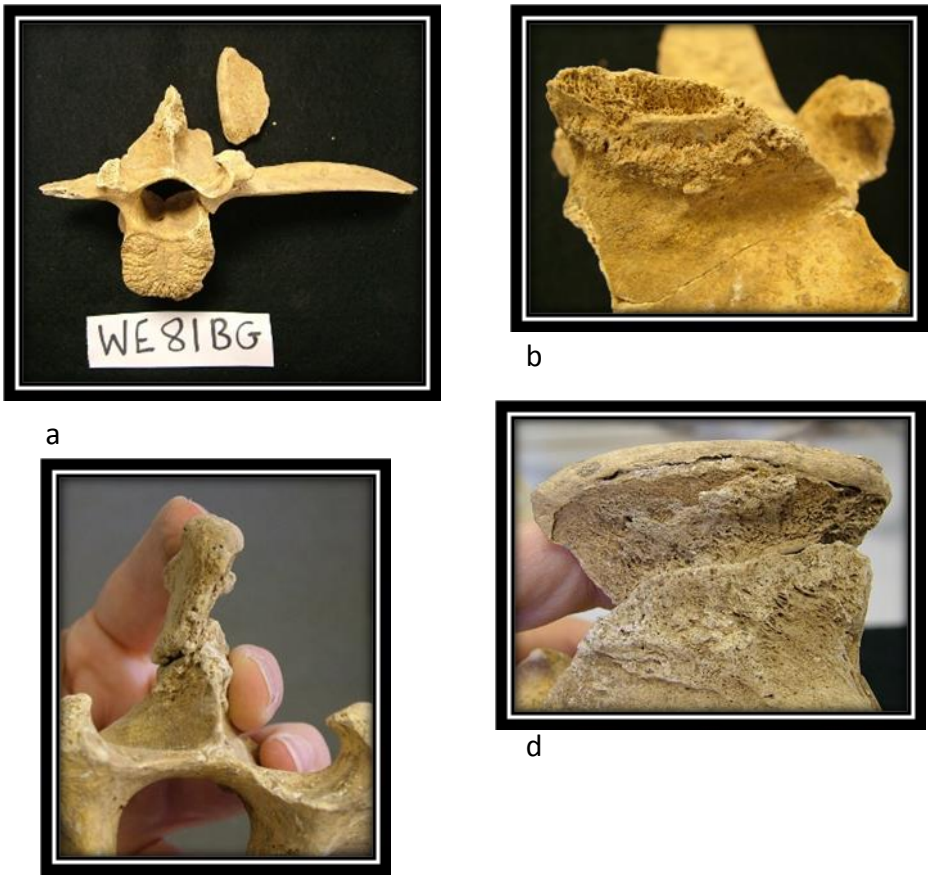
a b

Figure 9.61 Periosteal new bone formation on the visceral surface of several ribs (a), with close-up view of the new bone formation (b) (Photo: Author)



a b

Figure 9.62 Caudal vertebra with an enlarged foramen visible within the vertebral foramen (a) and also on the ventral side of the outer body (b) (Photo: Author)



a b c d

Figure 9.63 Non-union of a fracture to a lumbar vertebra (a). Callus formation can be seen on both fragments but union has not occurred (b, c and d) (Photo: Author)

Summary and Differential Diagnosis

This ABG possesses the highest frequency of pathological lesions identified of all the ABGs recorded from Wetwang Slack. The aetiologies suggested by the lesions are as follows: infection, trauma, periodontal disease and arthropathy. The plaques of woven bone on the visceral surfaces of the ribs indicate the presence of an active respiratory infection at death. The plaques identified on the vertebral bodies could also be infectious in origin. However, they could also reflect trauma to the vertebral column, possibly affecting the anterior longitudinal ligament. The fractured lumber vertebra may be the result of a fall or could be torsion related with pressure on the supraspinous ligament laterally displacing the spinous process. If this was the case, it could be associated with traction – the animal was identified as a possible male and arthropathy in the foot bones could potentially support this, although other characteristic lesions affecting the metapodia are absent, for example, asymmetry of the distal condyles (see Bartosiewicz *et al.* 1997). Whatever the cause of the fracture, the callus formation indicates the animal was not slaughtered immediately, but was slaughtered or died soon after. As with WE 8 AQ, enlarged foramina affecting the vertebrae were also observed; the most extreme case affecting a caudal vertebra. This example may reflect the merging of the two basi-vertebral foramina within the vertebral foramen. However, the outlet on the ventral side of the vertebral body is also enlarged, dismissing this as a purely developmental feature.

The remaining ABGs

The seven remaining ABGs were juvenile. With the exception of WE 300 MS and WA 55 CA, they all possessed solely proliferative lesions consisting of localised periostosis affecting the appendicular, axial and cranial regions of the skeleton. Skeletons WE 304 NY, WE 300 MS and WA 55 CA all had plaques of woven new bone on the ribs and WE 166 DG displayed evidence for endostosis. Bone lysis was most marked in WA 55 CA, with porous, lytic lesions within the vertebral foramen of two vertebrae along with an enlarged foramen in a third. The woven bone affecting the ribs like those affecting the more mature skeletons indicates an active respiratory infection at death. The solitary example of endostosis was observed on a non-diagnostic long bone fragment. This may have been due to osteomyelitis, but without the rest of the skeletal element, it is impossible to be sure. However, the skeleton was relatively complete and this was the only example of pathology noted, ruling out a systemic infection, unless the young animal succumbed prior to further skeletal involvement. The resorption of the bone within the vertebral foramen of WA 55 CA is intriguing. Due to the young age of the animal, osteoporotic change can be categorically ruled out. Therefore, infection, nutritional deficiency and metabolic disorder remain the prime candidates as a suspected aetiology, especially as it deemed not to be a taphonomic effect. The slightly enlarged foramen illustrates that this phenomenon is not restricted to more mature individuals. Whether it is related to an infection or just represents normal variation in this case is debatable.

Sheep/Goat ABGs

A total of seven sheep/goat ABGs were recorded (Table 9.16). Six of these were sheep and one was identified as goat. The majority were at least a year old, with the exception of WT 216 FH. The locations of these ABGs in relation to the settlement features at Wetwang Slack are indicated in Figure 9.64. Five ABGs were located within the boundaries of the ladder enclosure. The remaining two were located to the east and west of the enclosure, just within the southern boundary.

Table 9.16 Sheep/goat ABGs: Age at death and sex determination

Context Number	Age Estimation in months (epiphyseal fusion & tooth eruption)	Tooth Wear (mandible wear score)	Sex Determination	Pathological?
WE 527 XW	>36-42	32-37	-	Y
WS 516 QO	>36-42	-	F	N
WE 727 ADB	<36-42	38	-	N
WE 513 WE	(15-24) – (36-42)	-	-	N
WE 365 ACD	(15-24) – (18-28)	21-23	-	Y
WE 220 LD*	>11-13	-	M	Y
WT 216 FH	(6-8) – (10)	10-11	M?	Y

*goat

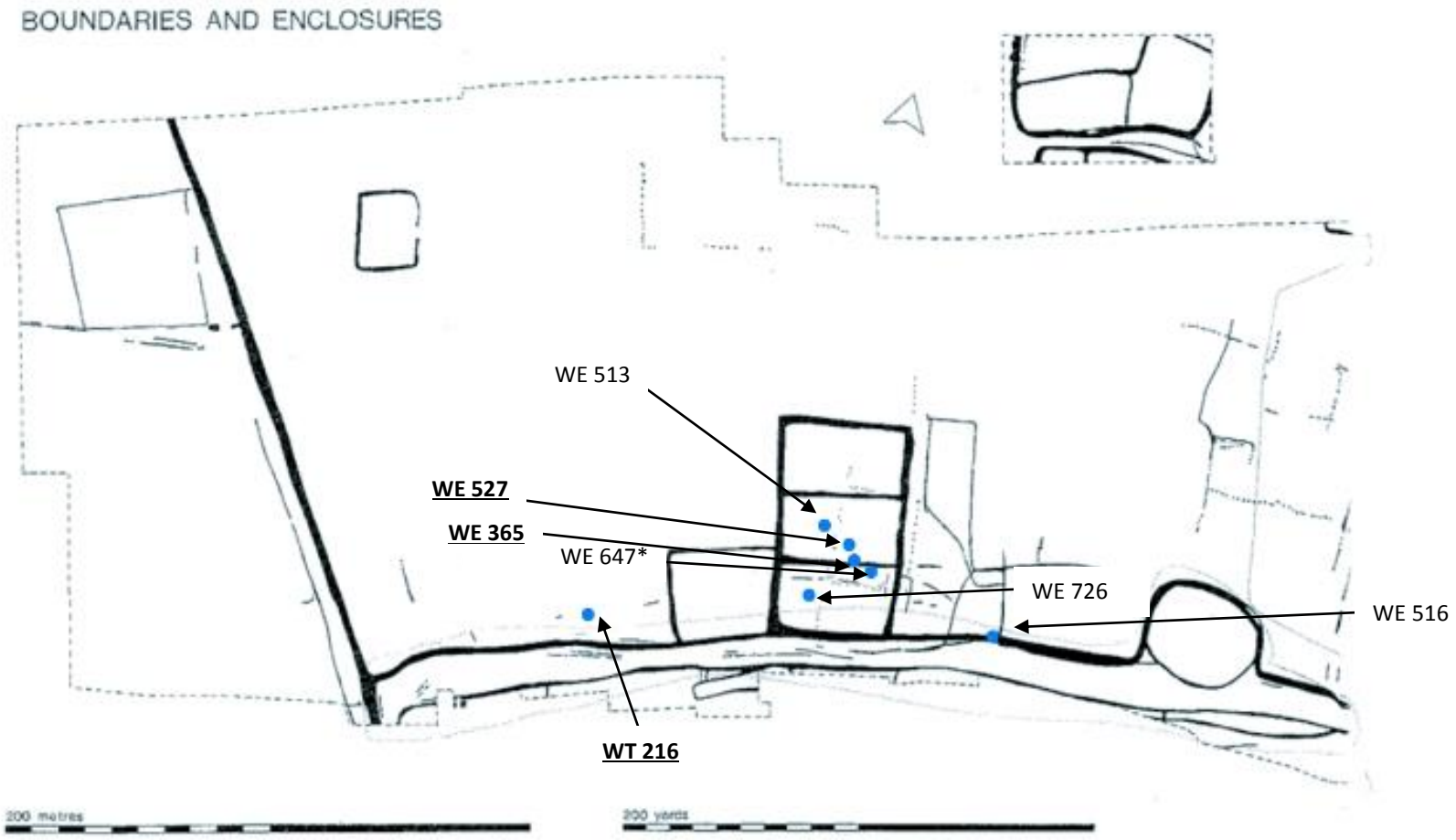


Figure 9.64 Distribution of sheep/goat ABGs with context labels at Wetwang Slack. The pathological ABGs are bold and underlined. (Adapted from Dent n.d: figs 9.1 & 12.1 and Scott n.d: fig 1, with additions)
*ABG not located for recording
Location of WE 220 is not shown

Palaeopathology

Four of the seven ABGs (57%) were pathological (Table 9.17). The skeletons were all largely complete and in a fair to good condition (Figure 9.65). However, none were selected for aDNA analysis. The different types of lesion identified and their distribution across the skeletons are presented in Figures 9.66 & 9.67. There was a significant difference in the skeletal distribution of pathological lesions throughout the skeleton at $\alpha = 0.05$ ($X^2 = 17.29$, $p = .0006$, $p < 0.05$, d.f. = 3). This indicates that the distribution is unlikely to be due to chance.

Table 9.17 The frequency of lesion types identified

Sheep/Goat	Frequency of Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
WE 527 XW	1	4	-	-	-	3
WE 365 ACD	2	-	-	3	-	-
WE 220 LD*	1	8	-	3	1	-
WT 216 FH	-	2	-	-	-	-

*Goat ABG

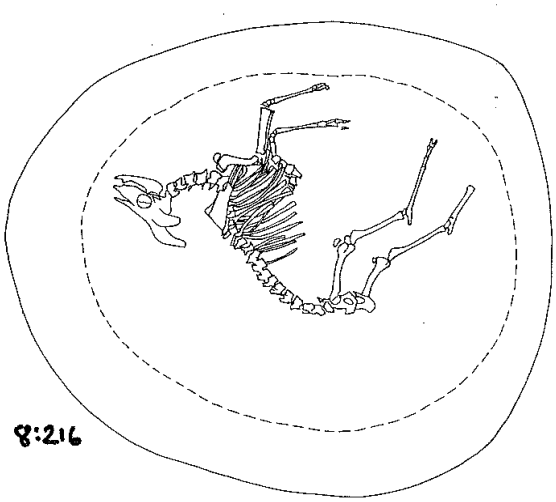
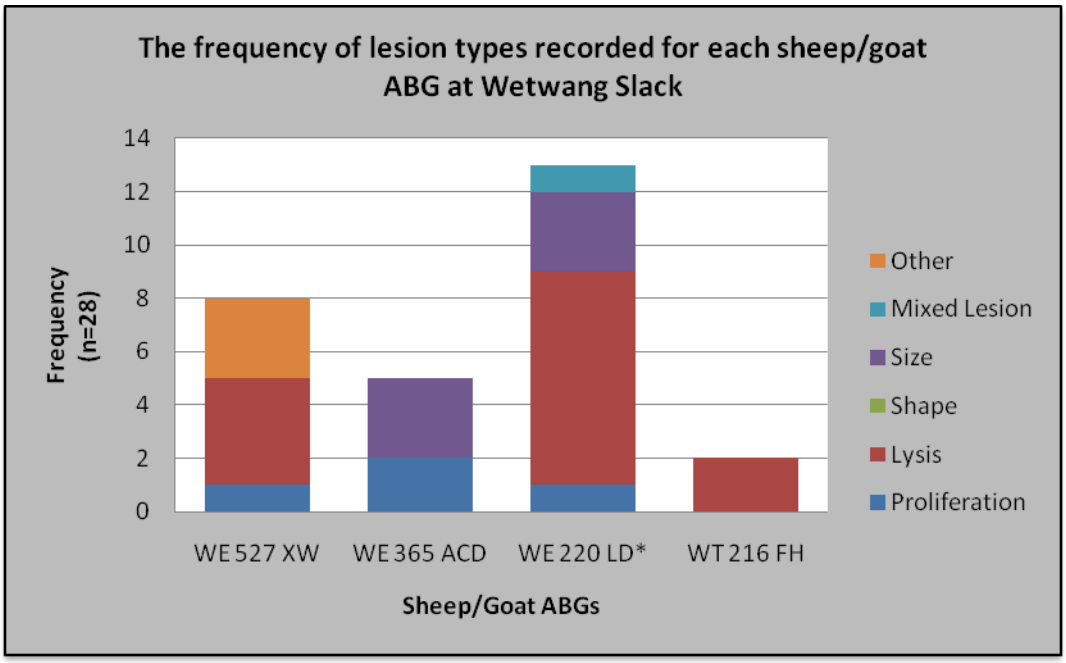
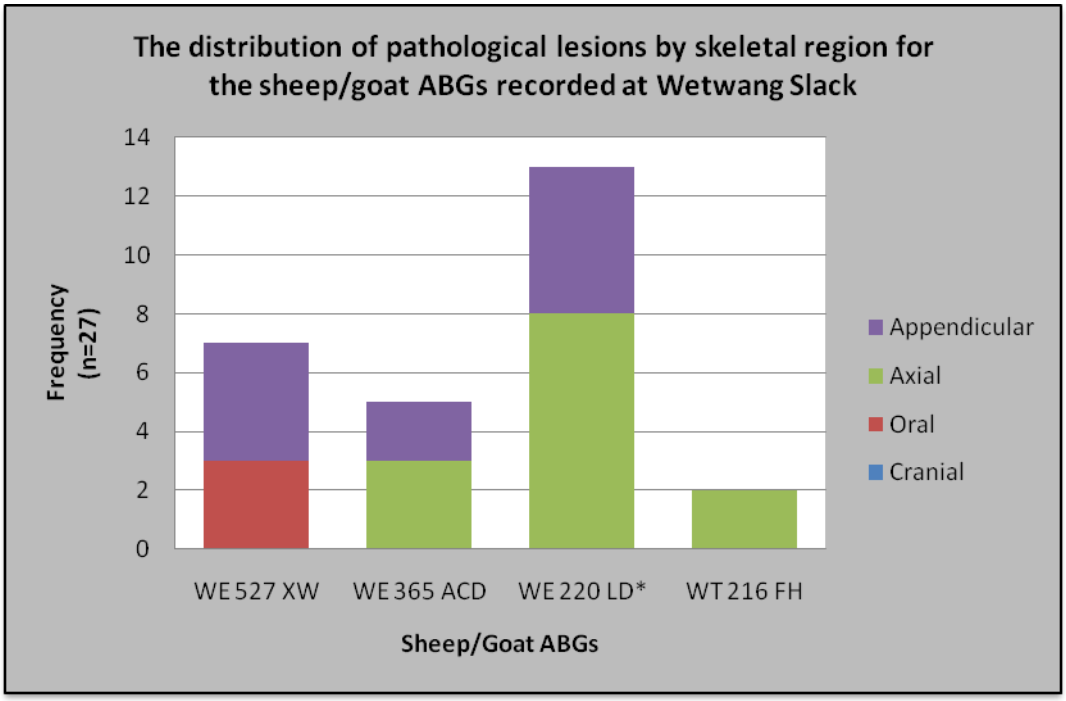


Figure 9.65 Plan of WT 216 FH *in situ* (Dent n.d: fig 9.2)



*Goat ABG

Figure 9.66 Sheep/Goat ABGs: The frequency of lesion types



*Goat ABG

Figure 9.67 Sheep/Goat ABGs: The distribution of pathological lesions across the skeleton

The single goat skeleton possessed the highest frequency of pathological lesions (n=13), of which 62% were associated with bone lysis. There were five instances of porous, lytic lesions within the vertebral foramen of two thoracic and three lumbar vertebrae, one of the latter also coupled with an enlarged foramen. Enlarged foramina were also observed within the sacrum and a cervical vertebra. The other instances of bone loss were as follows: pitting/porosity of the left astragalus, particularly the medial aspect of the trochlea; osteochondrosis manifesta affecting the proximal epiphysis of the left metacarpal and an irregular lesion perforating the epiphysis of the right metacarpal. A solitary example of periostosis was recorded on the proximal, cranial aspect of the femoral diaphysis with a mixed lesion (both porosity and new bone formation observed) affecting the distal condyles of a humerus. The sheep skeletons displayed a variety of lesions affecting the axial, appendicular and oral regions. Increased porosity was noted in the distal metapodial diaphyses in the oldest sheep recorded along with abnormal attrition. Periostosis was observed on the radius and a metacarpal, along with three enlarged foramina in WE 365 ACD, and, finally, pitting was identified within the acetabulum and the spinal canal of a lumbar vertebra in WT 216 FH, although the latter may have been exacerbated by taphonomic agents. The suspected aetiologies associated with these lesions are difficult to ascertain. Infection and trauma are both possibilities for the localised examples of periostosis. Pitting and porosity affecting the joint surfaces of the appendicular skeleton as well as a similar lesion on the acetabulum could be associated with arthropathy. The porous, lytic lesions observed within the vertebral foramen of

the goat could be related to infection, a nutritional deficiency or metabolic disorder.

Pig ABGs

A total of four pig ABGs were recorded (Table 9.18). The majority were juvenile, with the oldest at least 12 months at death. Only the location of one of these ABGs in relation to the settlement features at Wetwang Slack is known (Figure 9.68). This ABG was located within the boundaries of the ladder enclosure.

Table 9.18 Pig ABGs: Age-at-death and sex determination

Context Number	Age Estimation in months (epiphyseal fusion & tooth eruption)	Tooth Wear (mandible wear score)	Sex Determination	Pathological?
WS 342 MJ*	At least 12	20	-	Y
WT 164 DE	<12	15-16	-	Y
WE 734 ADF	7-12	17	-	N
WE 220 LE	(4-6) – (12)	7-8	-	Y

***Sampled for aDNA**

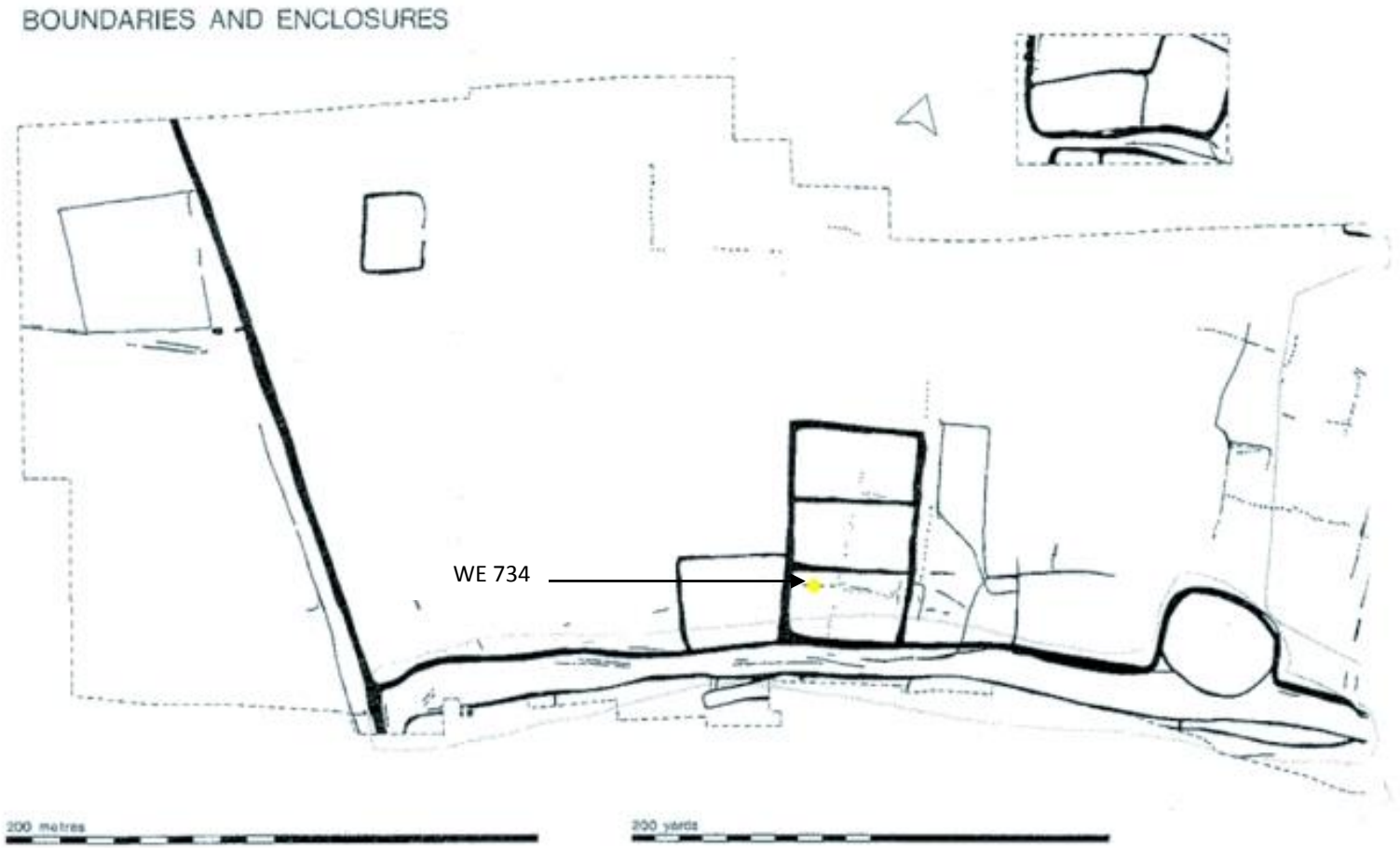


Figure 9.68 Distribution of the only pig ABG with a context label at Wetwang Slack. (Adapted from Dent n.d: figs 9.1 & 12.1 and Scott n.d: fig 1, with additions)
Locations of WS 342 MJ, WT 164 DE and WE 200 LE (all pathological) are not known

Palaeopathology

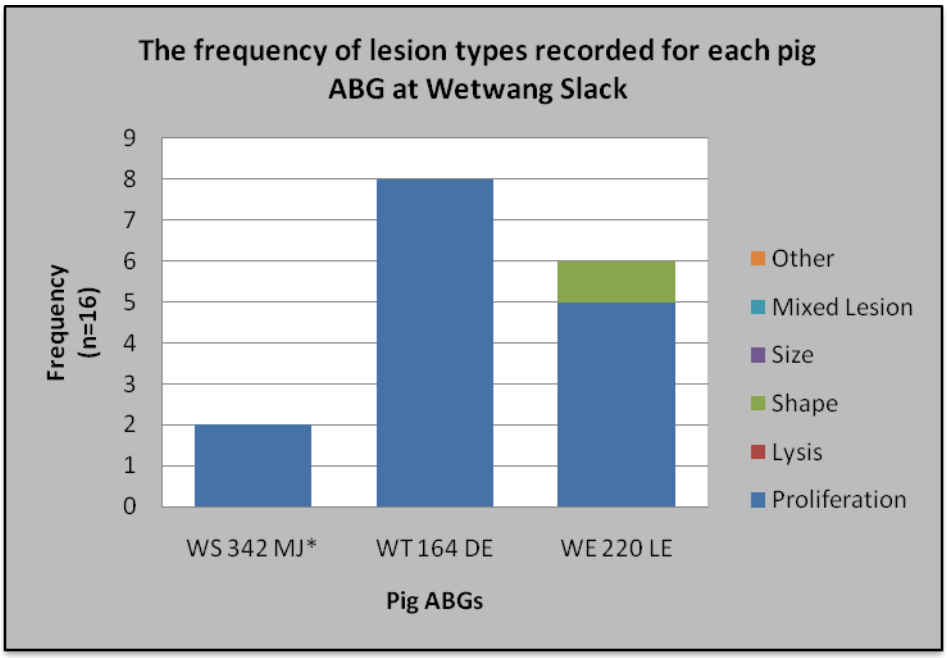
Three of the four ABGs (75%) were pathological (Table 9.19). The skeletons were semi-complete and in a fair to good condition. One was selected for aDNA analysis (section 9.7). The different types of lesions identified and their distribution across the skeletons are presented in Figures 9.69-9.70. There was no significant difference in the skeletal distribution of pathological lesions throughout the skeleton at α = 0.05 (X^2 = .09, *p* =.7630, p > 0.05, d.f. = 1).

Table 9.19 Pig ABGs: The frequency of lesion types

Pig	Frequency of Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
WS 342 MJ*	2	-	-	-	-	-
WT 164 DE	8	-	-	-	-	-
WE 220 LE	5	-	1	-	-	-

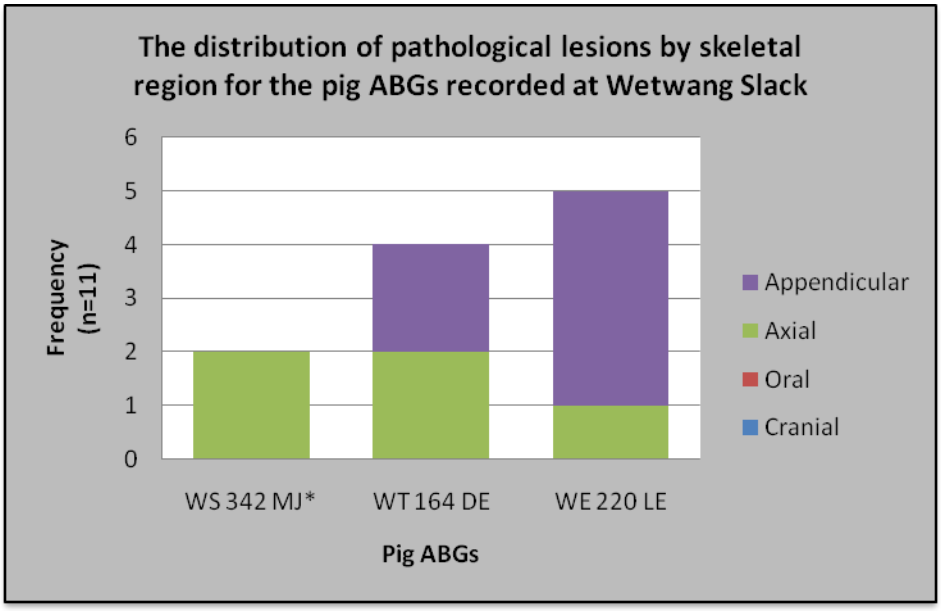
***Sampled for aDNA**

The overwhelming majority of pathological lesions recorded were associated with bone proliferation (94%); the other lesion was associated with abnormal shape. The lesions affected the appendicular and axial skeletons almost equally. WS 342 MJ and WT 164 DE had woven bone on the visceral surfaces of a total of eight rib fragments. Periostosis was also observed on an ulna, scapula blade, tibia, radius, metapodial and most markedly, a calcaneus (Figure 9.71).



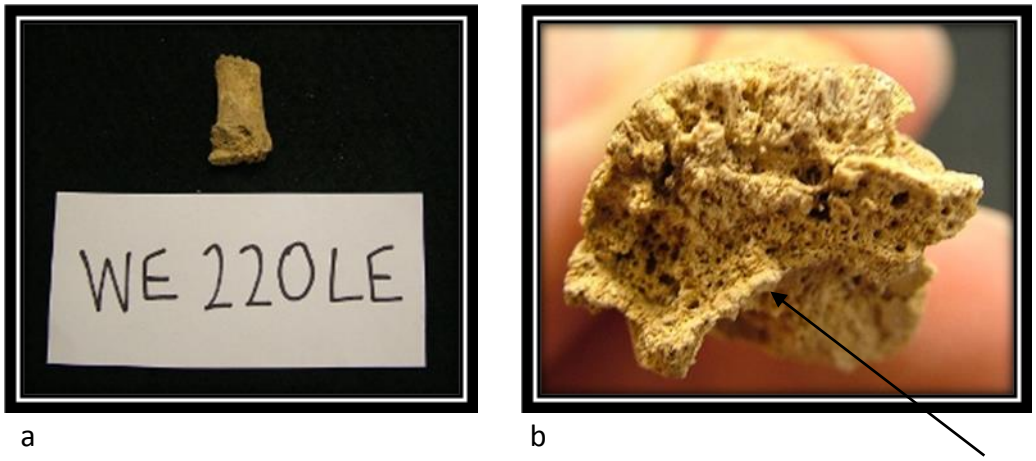
***Sampled for aDNA**

Figure 9.69 Pig ABGs: The frequency of lesion types



***Sampled for aDNA**

Figure 9.70 Pig ABGs: The distribution of pathological lesions by skeletal region



a b

Figure 9.71 Pig calcaneus with exuberant new bone proliferation on the lateral shaft (a). The edge of the original cortex can be seen illustrating the depth of the deposited new bone (see arrow) (b) (Photo: Author)

The plaques of woven bone on the visceral surfaces of the rib fragments indicate the presence of active respiratory infection at death. The localised instances of periostosis on the appendicular skeleton could be associated with either infection or trauma. The exuberant new bone proliferation observed on the calcaneus is porous and woven in appearance. The two main differential diagnoses for this type of pathology include trauma and neoplasm. This large deposition of new bone could represent a fracture callus. If this was a primary malignant bone tumour, for example, an osteosarcoma, one would expect the periosteal response to be more spiculed, forming the characteristic 'sunburst' appearance (section 4.5).

Horse ABGs

A total of four horse ABGs were recorded (Table 9.20). All were mature individuals with one male identified. Only the location of two of these ABGs in relation to the settlement features at Wetwang Slack is known (Figure 9.72). One is on the eastern

boundary of the ladder enclosure and the other to the south-east of the enclosure close to the southern settlement boundary.

Table 9.20 Horse ABGs: Age-at-death and sex determination

Context Number	Age Estimation in months (epiphyseal fusion & tooth eruption)	Crown Height (yrs)	Sex Determination	Pathological?
WS 482 RY	>50	13-14	-	Y
WE 66 AP*	>50-60	11-13	-	y
WE 64 AR*	>50-60	8-9	M	Y
WE 65 AO	<60	-	-	Y

***Sampled for aDNA**

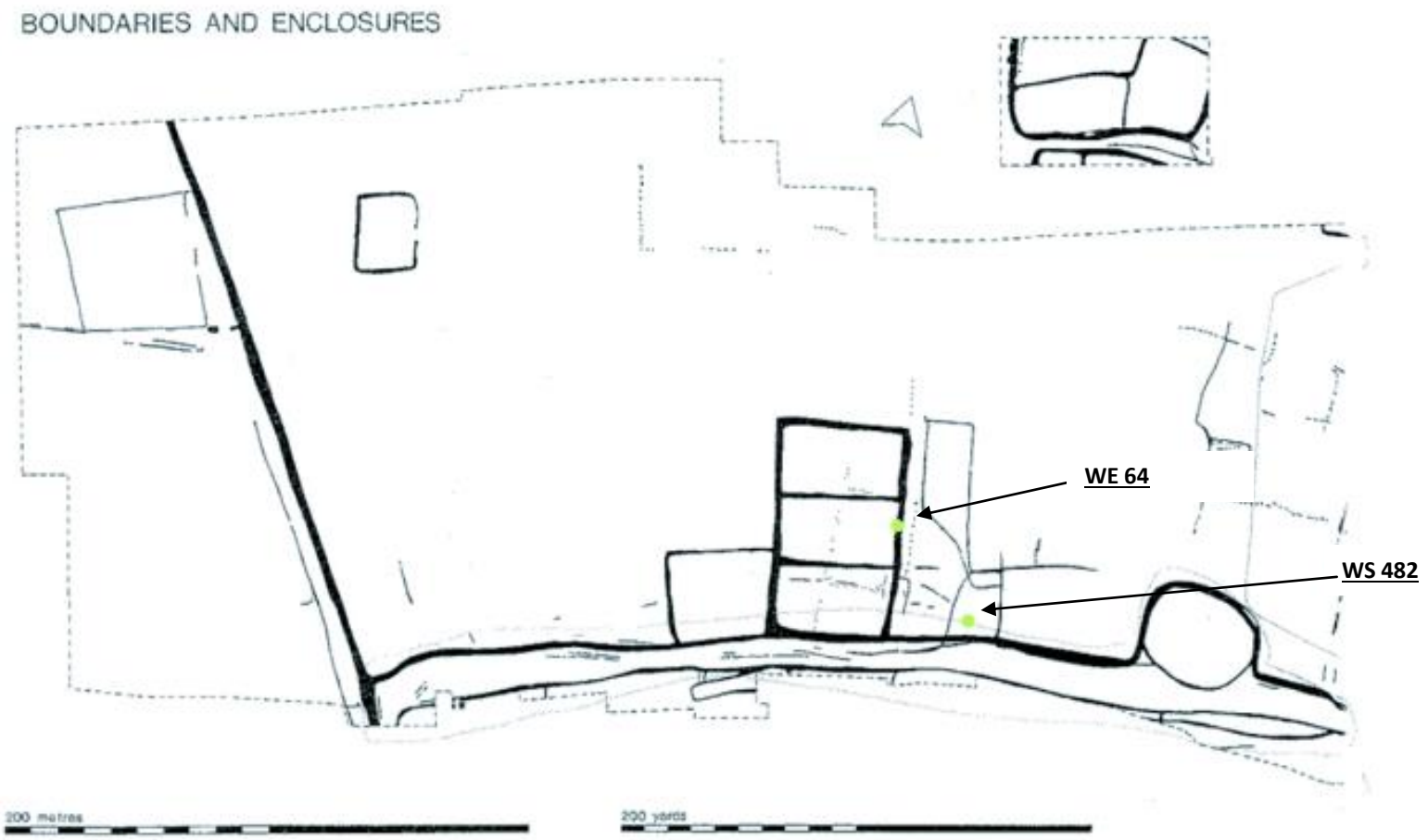


Figure 9.72 Distribution of horse ABGs with context labels at Wetwang Slack. Both ABGs shown here were pathological. (Adapted from Dent n.d: figs 9.1 & 12.1 and Scott n.d: fig 1, with additions)
Locations of WE 66 AP and WE 65 AO are not known

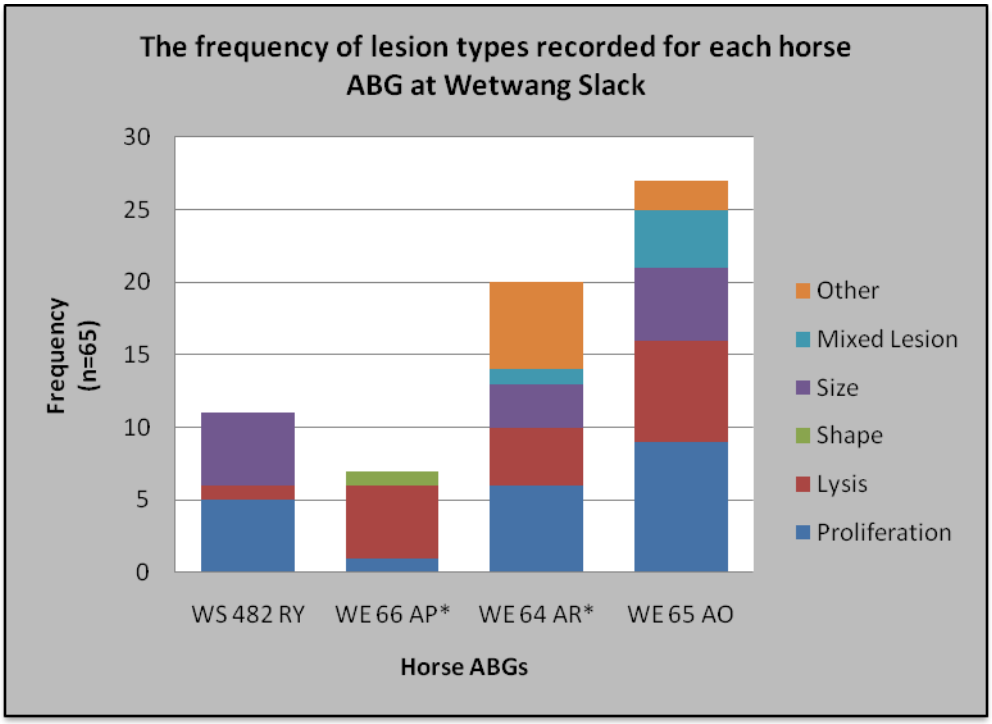
Palaeopathology

All four ABGs horses were pathological (Table 9.21). The skeletons were semi-complete and in a fair-good condition. Two (WE 64 AR and WE 66 AP) were sampled for aDNA analysis based upon their pathological lesions (section 9.7). The different types of lesion identified and their distribution across the skeletons are presented in Figures 9.73 & 9.74. There was a significant difference in the skeletal distribution of pathological lesions throughout affected skeleton at $\alpha = 0.05$ ($X^2 = 8.32$, $p = .0039$, $p < 0.05$, d.f. = 1). This indicates that the distribution is unlikely to be due to chance.

Table 9.21 Horse ABGs: The frequency of lesion types

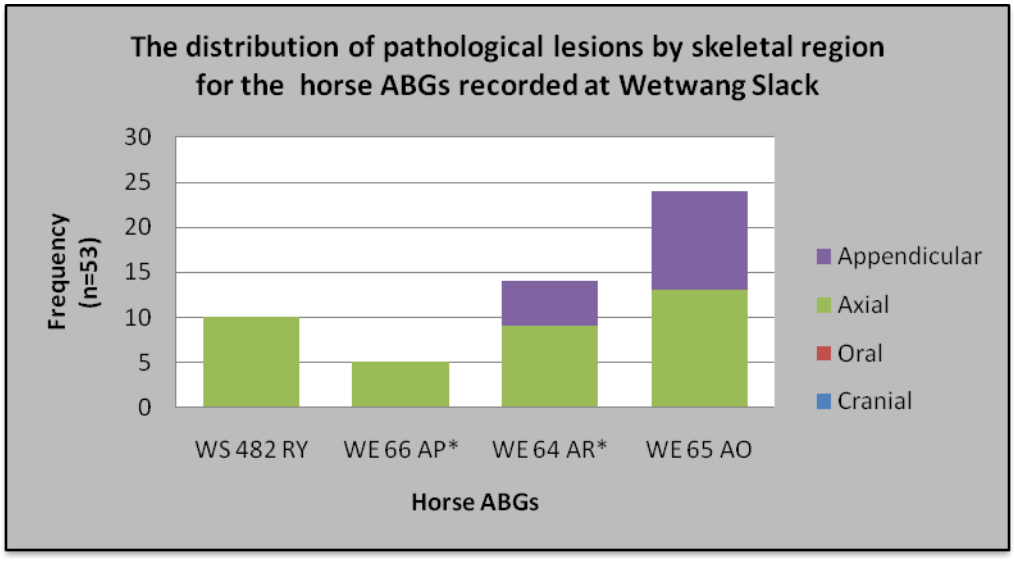
Horse	**Frequency of Lesion Type**					
	Proliferation	**Lysis**	**Shape**	**Size**	**Mixed Lesion**	**Other**
WS 482 RY	5	1	-	5	-	-
WE 66 AP*	1	5	1	-	-	-
WE 64 AR*	6	4	-	3	1	6
WE 65 AO	9	7	-	5	4	2

***Sampled for aDNA**



***Sampled for aDNA**

Figure 9.73 Horse ABGs: The frequency of lesion types



***Sampled for aDNA**

Figure 9.74 Horse ABGs: The distribution of pathological lesions by skeletal region

The two most frequent lesion types recorded were associated with bone proliferation (32%) and bone lysis (26%). The pathological lesions were identified predominantly on the axial skeleton (70%), with just under a third (30%) affecting the appendicular skeleton.

WE 64 AR

This horse skeleton, a male, was aged 8-9 years at death and possessed the second highest frequency of pathological lesions (n=20). The skeleton was relatively complete and articulated (Figure 9.75); it was located on the eastern boundary of the ladder enclosure (Figure 9.72).

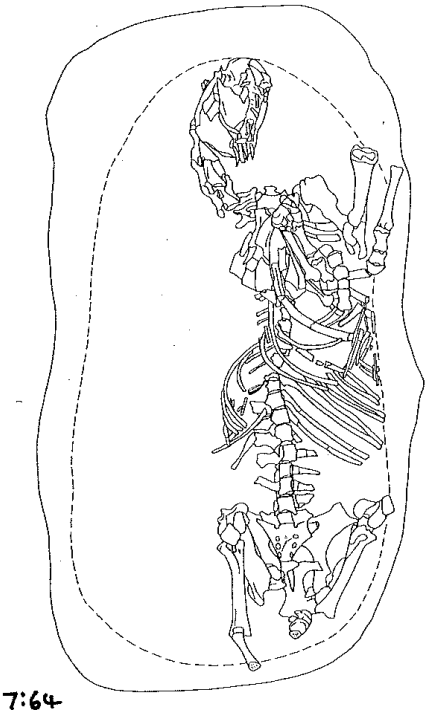


Figure 9.75 Plan of WE 64 AR *in situ* (Dent n.d: fig 9.2)

Lesions associated with new bone proliferation and lesions categorised as 'other' dominated the identifications, representing (when combined) 60% of the pathological lesions recorded. The greater majority of lesions affected the axial skeleton (64%). Those lesions recorded as 'other' comprised four examples of micro-fractures affecting ossified fragments of costal cartilage; an unidentified fragment (possibly pelvis) displaying a fracture and a malformed vertebral spinous process.

The most striking pathological condition identified affected several thoracic vertebrae. The most severely affected vertebra possessed evidence of both bone proliferation and bone loss suggestive of osteomyelitis. The spinous process was grossly swollen, a fresh break allowing for the layers of compact new bone to be clearly seen in cross-section (Figure 9.76). Although the new bone was 'compact' the cortical bone surface was still pitted in places. In addition to this, a substantial cloaca measuring 0.5cm x 1cm and possessing a semi-circular shape was present at the dorsal tip of the spinous process, evident on both sides of the spinous process. This region was clearly dysplastic with the tip displaced laterally. There are two possible scenarios for this displacement: 1) a cloaca formed in the proximal spinous process leading to structural compromise and subsequent collapse, 2) the dorsal tip of the spinous process was subject to trauma and displacement leading to osteomyelitic infection. The radiograph in Figure 9.76, illustrates a sclerotic response in this region with the edges of the lytic lesion appearing somewhat ragged, despite the fact that macroscopically the margins of the cloaca on both

sides of the spinous process appear rounded and remodelled. The vertebral body associated with this spinous process was unaffected. The lower regions of the spinous process were also unaffected, with the exception of some enthesophytes and some shallow irregularly shaped cavities on the caudal face. The latter may possibly be associated with the insertion of the ligament. A further three spinous processes were recorded as swollen in size and these possibly belonged to adjacent vertebrae. These pathological lesions, particularly affecting the spinous processes are very similar to those described by Kelly *et al.* (1972) (section 3.9.3).

Other lesions recorded included: symmetrical enthesophytes or ossified soft-tissue) on the caudal distal femoral diaphyses; enlarged foramina noted within the spinal canals of three thoracic vertebral bodies; symmetrical shallow lesions affected the distal humeral condyles, possibly reflecting osteochondrosis or a developmental cortical defect, and a small, localised area of bone resorption noted on a sternum fragment. The most extreme example of bone lysis was observed on the 'wall' (cranial aspect) of the left third phalanx (Figure 9.77). The distal region of the wall surface was completely necrotic leaving a 'scalloped' appearance.

a

c

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b

d

e

f

Figure 9.76 WE 64 AR: Osteomyelitis of a thoracic spinous process (a, b). Swelling of the dorsal region of the spinous process with cloaca (c, d & e). The layers of new bone on top of the original cortex can be clearly seen (see arrow, image e). (Photo: Author, Radiograph: Dr. J. Buckberry, taken at 45 kV with exposure of 2 seconds)

Figure 9.77 WE 64 AR: Extensive necrosis of the cranial aspect of the third phalanx (Photo: Author)

Summary and Differential Diagnosis

The osteomyelitis evident in the thoracic spinous process could be the result of trauma or infection. The lesions may reflect a condition referred to as fistula withers, a condition associated with the inflammation and rupture of the supra-spinous bursae (section 4.2.1). The condition has also been associated with both brucellosis and actinomycosis (section 4.2.1). Tuberculosis would also be a possibility; contrary to the pattern associated with human skeletal involvement, the posterior portions of the vertebrae can be affected in animals. In addition, similar lesions were observed in a modern horse confirmed as having *M. bovis* (see Kelly *et al.* 1972). Porous, lytic lesions within the vertebral foramen of the sacrum could be related to infection also, along with the enlarged foramina. The extensive necrosis of the third phalanx was attributed to 'foot rot' by Scott in her original analysis (Scott n.d). However, 'foot-rot', or 'foul-in-the-foot' as it is also known, predominantly affects cattle, not horses. The 'scalloped' margins of the lesion could suggest an infective organism, which may have gained entry via a penetrating

injury. Whatever the aetiology, the horse would have been lame and was most likely slaughtered as a result, if death did not occur beforehand.

WE 66 AP

This horse was aged 11-13 years at death and possessed the least number of pathological lesions (n=7) of all the horse ABGs. The skeleton was located to the south-east of the ladder enclosure, just within the southern settlement boundary (Figure 9.72). Lesions associated with bone lysis dominated the pathological conditions recorded (71%). All lesions affected the axial skeleton. The atlas vertebra displays both bone proliferation and bone lysis, possibly indicating infection (Figure 9.78). The dorsal surface of the cranial articulating facets displayed what appeared to be 'compact' new bone formation associated with non-perforating irregular lytic lesions. The new bone may actually represent exotoses or enthesophytes associated with the articulation between this vertebra and the foramen magnum, as opposed to a periosteal response. Nevertheless, the lytic lesions are multiple and symmetrical but relatively shallow.

a

b

c

Figure 9.78 WE 66 AP atlas vertebra (a). Multiple non-perforating lytic lesions (c) associated with compact new bone formation on the dorsal aspect of the cranial articulation of an atlas vertebra (b) (Photo: Author)

Other lytic lesions were also recorded on the ilium of the pelvis; the same element was also dysplastic, with an acetabulum slightly flared. In addition to this, porous, lytic lesions were noted in the transverse foramina positioned on the lateral sides of two cervical vertebrae. A porous, lytic lesion was also noted within the vertebral foramen of a sacral vertebra.

Summary and Differential Diagnosis

The lesions affecting the atlas vertebra may relate to an inflammatory condition of the supra-atlantal bursa, referred to as poll evil (section 4.2.1). As with fistula withers, both brucellosis and actinomycosis have been associated with this

condition. However, trauma to the poll region can also lead to inflammation and resulting osseous lesions. The skull was highly fragmented but no pathological lesions were observed on the occipital region or around the foramen magnum. Bone resorption affecting the transverse foramina of two cervical vertebrae may be related to infection or possibly a nutritional deficiency. The latter, however, is unlikely as the resorption is localised within the transverse foramen and is, therefore, likely to be associated with blood flow. It is also unlikely that this lesion is associated with osteoporosis, as the other skeletal elements were unaffected, and the bones were not unusually light in weight.

The remaining ABGs

WE 65 AO possessed the highest number of recorded pathological lesions (n=27). Bone proliferation comprised 33% and bone lysis 26 % of the lesions recorded. The axial and appendicular regions dominated the lesion locations with the axial skeleton marginally more affected than the appendicular skeleton. The majority of bone proliferation was associated with vertebral enthesophytes. A small shallow lytic lesion on the articular surface (sustentaculum tali) of the calcaneus, also seen on the articulating astragalus, represents osteochondrosis. The presence of an enthesophyte and 'lipping' of the articular facet also affecting the calcaneus points towards joint stress/trauma and arthropathy. Osteochondrosis was also observed on the proximal epiphysis of a metacarpal; this skeletal element also displayed an enthesophyte on the caudal shaft associated with the 'side bone' (accessory metacarpal). Bone lysis coupled with some minor bone proliferation was recorded

on a third phalanx; potentially an early stage of the necrotic lesion illustrated in Figure 9.77. Pitting was identified on the proximal epiphysis of the first phalanx, the distal humeral condyle and also on the distal femur, specifically the medial side of the trochlea. Enlarged foramina were observed on five thoracic vertebral bodies. Two pathological caudal vertebrae were also recorded: one was dysplastic, possibly due to a well-healed fracture and the other possessed a shallow indentation in the articular facet – almost resembling a Schmorl's node. This could be a compression fracture, but the fact that it is a caudal vertebra and, therefore, is not load-bearing would seem to suggest another cause. Lastly, four tarsal bones (two left and two right) possessed symmetrical exotoses, lipping and pitting affecting the articular surfaces, indicating arthropathy in the hind legs. WS 482 RY possessed eleven pathological lesions, of which proliferation and size alteration formed the most frequent lesion types recorded. All the lesions were located in the axial skeleton. Ossification of the anterior longitudinal ligament was observed on a thoracic and lumbar vertebra. Compact bone was noted on the lateral side of a thoracic vertebral body, possibly representing well-ossified soft tissue. Another instance of ossified tissue, possibly associated with the supra-spinous ligament was also identified on the dorsal tip of the thoracic spinous process. Possible arthropathy of a rib head is suggested by the presence of bony exotoses around the margins of the head and, a small cavity in the articulating facet. This could potentially be trauma-related. Five thoracic vertebrae possessed enlarged foramina affecting the vertebral body, with two vertebrae also showing enlargement of the foramina within the vertebral foramen.

ABG Summary

The ABGs at Wetwang Slack date to the later Iron Age/early Romano-British period. A total of twenty were identified as pathological: cattle (n=9), sheep/goat (n=4), pig (n=3) and horse (n=4). A mixture of proliferative and lytic lesions were observed, primarily affected the axial and appendicular skeleton. With the exception of pig, the distribution of pathological lesions throughout the skeletons of the other species (cattle, sheep/goat and horse) was significantly different at $\alpha = 0.05$. There was no discernible pattern associated with the location of the burials, with Scott concluding that they may have been diseased stock and buried where they fell (Scott n.d).

9.6 Barton Field, Tarrant Hinton, Dorset

Barton Field was selected because of the evidence for *M. tuberculosis* in the human population (section 5.7.2). The faunal assemblage was recorded and reported on by R.W Peck (Peck 2006). In addition to the disarticulated assemblage, a number of ABGs were also recovered (Peck 2006: 164). Unfortunately, apart from four ABGs that were excavated from definite Iron Age pits, the rest of the disarticulated assemblage could not be phased (section 5.7.2.1). As a result, the Iron Age/Romano-British assemblage was considered as a whole by Peck in his original analysis (Peck 2006:164) and by the present researcher in the following palaeopathological observations. The results from the disarticulated assemblage are presented in section 9.61 and the ABGs in section 9.6.2.

9.6.1 The Disarticulated assemblage

The assemblage totalled 6,292 fragments, of which 23% (n=1,472) was identifiable to species and skeletal element (Peck 2006:164). Data pertaining to the 'Number of Identified Specimens' (NISP) recorded is presented in Table 9.22 and Figure 9.79. Sheep/goat dominate the assemblage, accounting for 58% of the identified bones; cattle follow in frequency at 20%, with horse slightly more frequent than pig at 8% and 6%, respectively.

Table 9.22 Number of Identified Specimens at Barton Field (Data from Peck 2006: 164)

	IRON AGE/ROMANO-BRITISH	
SPECIES	**NISP**	**%NISP**
Cattle	288	20%
Sheep/Goat	850	58%
Pig	87	6%
Horse	122	8%
Deer sp.	38	2%
Dog	78	5%
Cat	9	1%
Total No. Identified	**1472**	**100%**
Total No. Unidentified	**4820**	**-**
TNF	**6292**	**-**

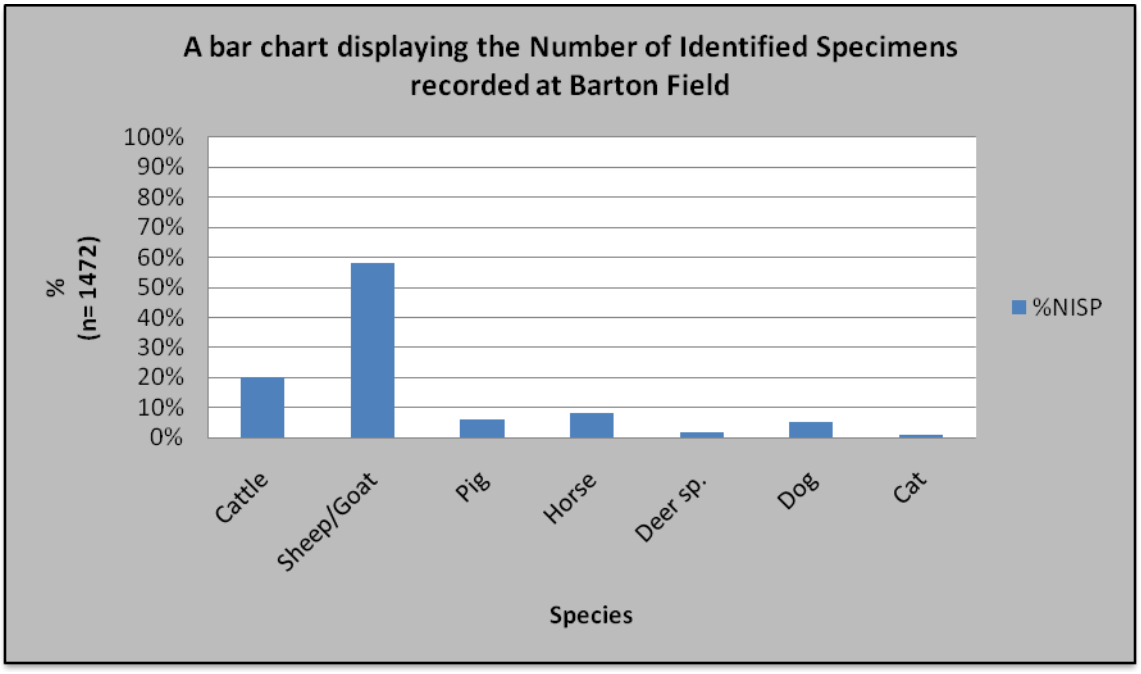


Figure 9.79 Number of Identified Specimens recorded at Barton Field (Data from Peck 2006: 164)

Palaeopathology

Seventy-eight types of pathology were recorded on 69 bones, equating to just 1% of the entire assemblage. Sheep/goat and cattle were jointly the most frequent species identified with palaeopathological lesions (30% each) (Figure 9.80). Although, the numbers of pathological bones was equal for both species, when viewed in the context of the overall NISP totals, cattle appeared to display a greater overall frequency of pathological bones. To test if there was any significant difference, a chi-square was conducted. This was significant at $\alpha = 0.05$, $X^2 = 14.07$, $p = .0002$, $p < 0.05$, d.f. = 1 (Appendix 4). Chi-square tests do not pin-point where the specific difference (if any) lies in the data; therefore, there are two possibilities for this significant result. Either the cattle at Barton Field were more pathological on average than sheep/goat or there were not as many pathological sheep/goat bones identified for some reason. Given the difference in NISP totals, the former explanation is suspected.

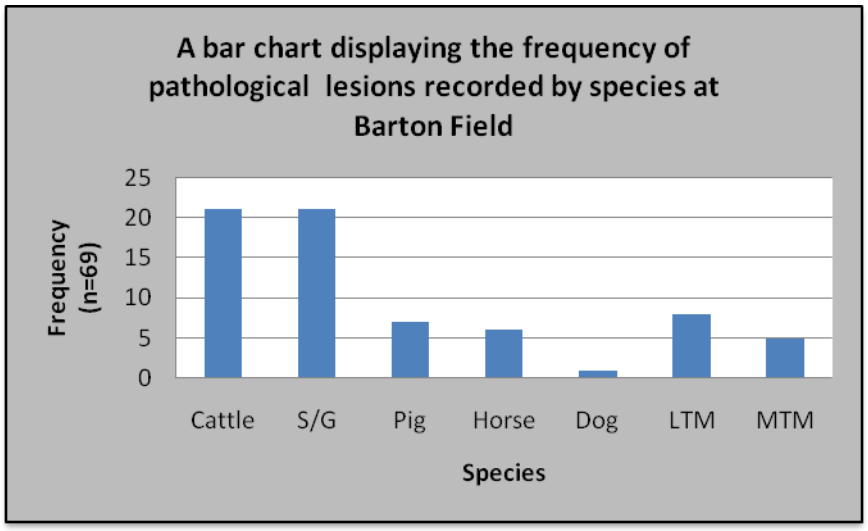


Figure 9.80 The frequency of pathological lesions recorded by species at Barton Field

A summary of palaeopathological lesion types

Table 9.23 and Figure 9.81 illustrate the frequency of pathological lesions by species for the assemblage at Barton Field. Abnormal bone proliferation (27%) and bone lysis (24%) represent the most frequent lesion types recorded, followed by 'other' (19%). Periostosis (67%) is by far the most prominent bone formation type, followed by osteophytes formation (22%), endostosis (7%) and syndesmophyte formation (4%). Lesions associated with osteochondrosis manifesta dominate the bone lysis lesion type (46%), followed by pitting/porosity (21%), space-occupying lesions (17%), porous, lytic lesions and lytic perforations (both 8%). The 'other' category comprised the following lesion types: fractures (37%), hypercementosis of tooth roots (16%), general trauma (11%), (fusion of horse accessory metapodial to the medapodial shaft and a deformed cattle horncore, possibly polled or broken), congenital/developmental defect (11%), abnormal attrition (11%), tooth impaction (5%), ventral margin disturbance (5%) and tooth misalignment (5%).

The remaining pathological types include three cases of abnormal bone size. These all consisted of enlarged foramina, affecting a cattle axis vertebra, distal cattle metatarsal and a horse lumbar vertebra. There were also five mixed cases: one cattle metacarpal displaying large and exuberant plaques of compact bone on the caudal proximal diaphysis associated with *myostitis ossificans traumatica*. The bone appears to have been fractured at the distal end, with evidence for disuse atrophy (Figure 9.82). The bone was well-healed but would have taken a substantial amount of time to do so as evidenced by the formation of compact bone around the blood vessels. Disuse atrophy is apparent in the dysplastic lower diaphysis, indicating the

lower left forelimb was not load-bearing for a time. This represents a severe injury for a large animal resulting in lameness. However, this animal appears to have been treated/managed. In addition, there was also a cattle metatarsal with marginal osteophytes located around the periphery of the proximal epiphysis, as well as localised pitting on the lateral articulating facet; two ankylosed horse tarsals with pitting and a number of lytic lesions; a sheep/goat skull displaying a healed depression fracture with lytic lesions to the frontal bone and a pig mandible displaying osteomyeltis, with new bone proliferation and a cloaca.

Table 9.23 Barton Field: Summary of pathological lesion types by species

Species Affected	**Lesion Type**					
	Proliferation	**Lysis**	**Shape**	**Size**	**Combination**	**Other**
Cattle	7	8	-	2	2	6
Sheep/Goat	6	10	-	-	1	5
Horse	3	-	-	1	1	1
Pig	6	1	-	-	1	-
Dog	-	-	-	-	-	1
LTM	4	2	-	-	-	5
MTM	1	3	-	-	-	1
TOTAL No.	**27**	**24**	**-**	**3**	**5**	**19**
TOTAL %	**35**	**31**	**-**	**4**	**6**	**24**

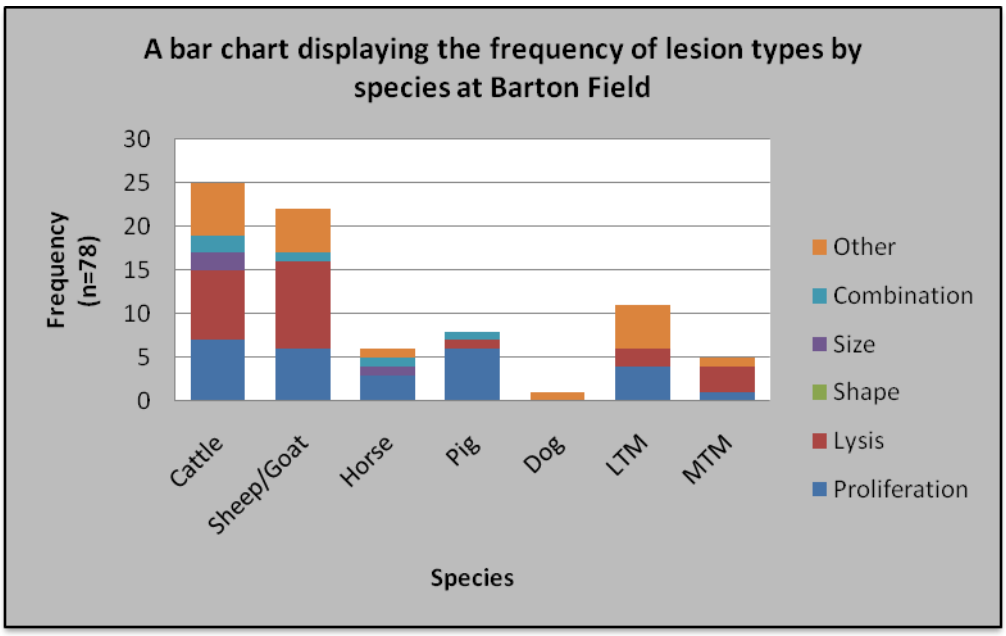


Figure 9.81 The frequency of lesion types by species at Barton Field

a b c

d

Figure 9.82 Cattle metacarpal: *Myostitis ossificans traumatica* (a, b & c). Evidence for disuse atrophy in lower diaphysis (d) (Photo:Author, X-ray: Dr. J. Buckberry)

A summary of palaeopathological lesion characteristics: suspected aetiologies

Table 9.24 and Figure 9.83 illustrate the frequency of pathological conditions recorded by species at Barton Field. Non-specific bone proliferation, potentially indicative of infection, was the most frequent category (24%), followed by other (17%), non-specific bone lysis (16%), trauma (16%), oral pathology (13%), arthropathy (8%), congenital (4%) and combination (3%).

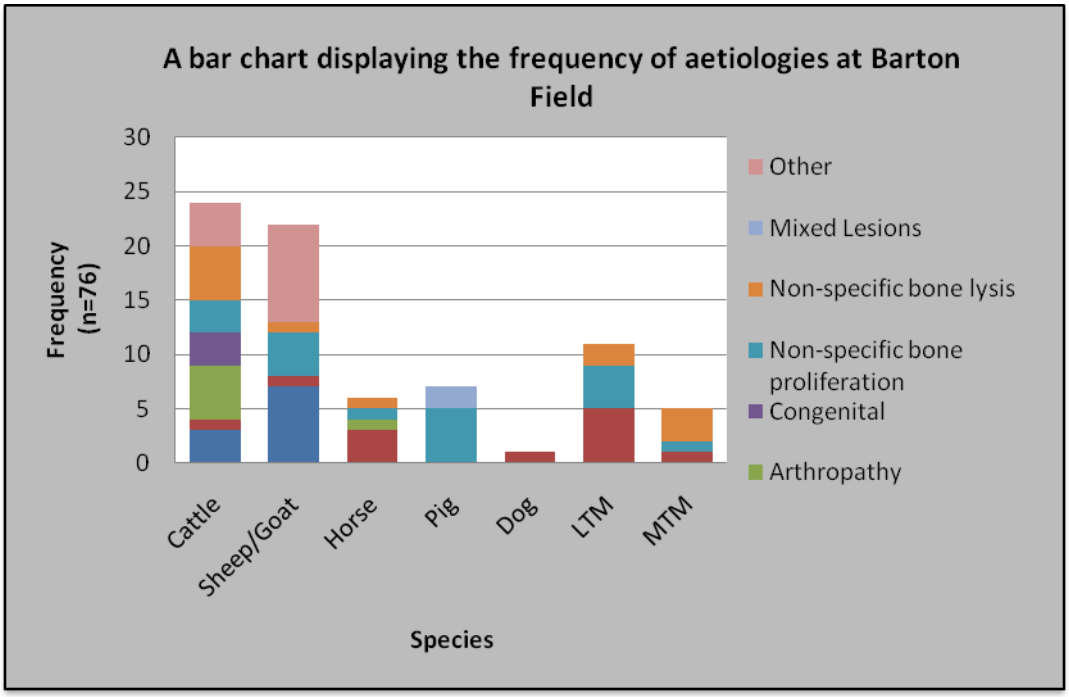


Figure 9.83 The frequency of aetiologies recorded by species at Barton Field

Table 9.24 Barton Field: Summary of aetiologies by species

Species Affected	General Aetiology Categories							
	Oral	Trauma	Arthropathy	Congenital	Infection?		Mixed lesion	Other
					Non-specific bone proliferation	Non-specific bone lysis		
Cattle	3	1	5	3	3	5	-	4
Sheep/Goat	7	1	-	-	4	1	-	9
Horse	-	3	1	-	1	1	-	-
Pig	-	-	-	-	5	-	2	-
Dog	-	1	-	-	-	-	-	-
LTM	-	5	-	-	4	2	-	-
MTM	-	1	-	-	1	3	-	-
TOTAL No.	**10**	**12**	**6**	**3**	**18**	**12**	**2**	**13**
TOTAL %	**13**	**16**	**8**	**4**	**24**	**16**	**3**	**17**

With the exception of oral pathology, trauma, other, non-specific bone proliferation and non-specific bone lysis, the other aetiologies were too lower in number for comparative statistical analyses. As with Wetwang Slack, the two most frequently identified species, cattle and sheep/goat, were selected to form the focus of several chi-square tests (Table 9.25, Appendix 4). The aim being to substantiate any differences observable in the data.

Oral pathology, trauma, other (specifically OCM) and non-specific bone proliferation were compared and no significant differences were observed at $\alpha = 0.05$ (Table 9.25). However, there was a statistically significant difference between cattle and sheep/goat for non-specific bone lysis, with sheep/goat displaying lower numbers of cases by comparison with cattle. It was impossible to run similar tests including any LTM and MTM data, as at Wetwang Slack, as the information had not been recorded in this manner by Peck (2006). Intra-species differences were also analysed, with particular attention paid to non-specific bone proliferation and non-specific bone lysis. There were no statistically significant differences in aetiology frequency for either cattle or sheep/goat at $\alpha = 0.05$ (Table 9.25). This is in contrast to the sheep/goat at Wetwang Slack.

Table 9.25 X^2 results: cattle and sheep/goat aetiologies

Aetiology (cattle vs. sheep/goat)	$X^2_{(1)}$	*P* value	H_0 Accept or reject?
Oral pathology	.12	.7317	Accept
Trauma	.65	.4215	Accept
Other (osteochondrosis manifesta)	.30	. 5849	Accept
Non-specific bone lysis	10.74	.0010	**Reject**
Non-specific bone proliferation	1.15	.2841	Accept
Sheep/goat: Non-specific bone proliferation vs. non-specific bone lysis	1.81	.1791	Accept
Cattle: Non-specific bone proliferation vs. non-specific bone lysis	.51	.4764	Accept

Evidence for Possible Infection and Differential Diagnosis

Non-specific bone proliferation and bone lysis, when combined, comprise 40% of the lesion types recorded. Apart from two cases of endostosis (11%), the rest of the bone proliferation was periostosis (89%). The appendicular, oral and axial regions of the skeleton were affected, with pig displaying the highest frequency of lesions of the appendicular skeleton (Figure 9.84). Unfortunately, there was not enough data to test the distribution of non-specific bone proliferation lesions throughout the skeleton. However, there was a statistically significant difference

identified at α = 0.05 (X^2 = 5.33, p=.0209, p < 0.05, d.f. = 1) when the appendicular and axial regions were compared, verifying this pattern in the data.

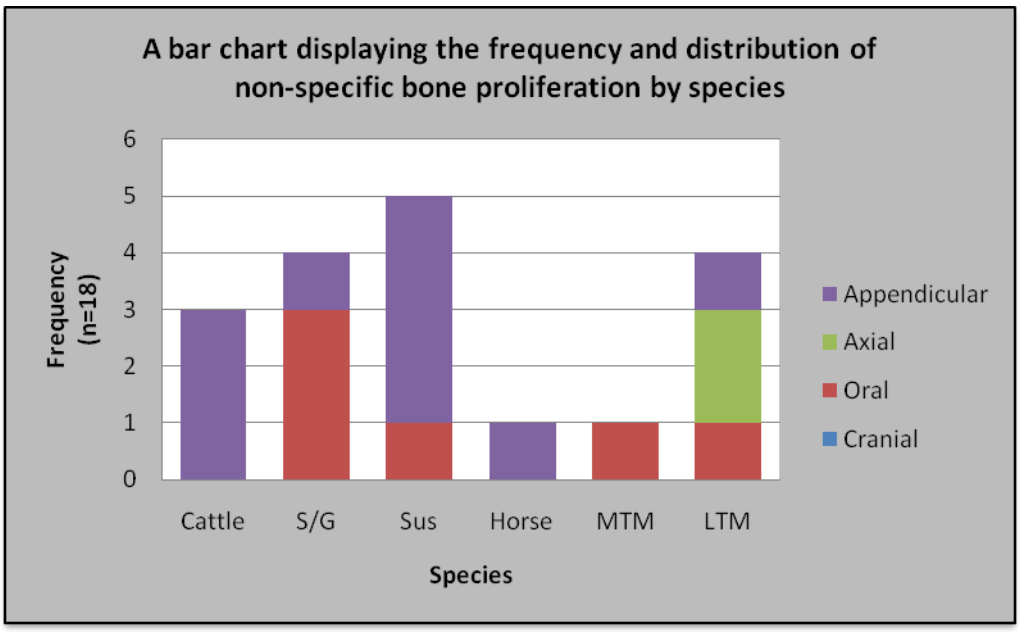


Figure 9.84 Non-specific bone proliferation by skeletal region at Barton field

Periostosis was recorded most frequently in the appendicular skeleton. Cattle, sheep/goat, pig, horse and LTM were affected. It consisted of plaques of new bone formation located on the long bone diaphyses and was localised in some cases but in others, more widespread. The majority of the new bone was woven in appearance, suggesting it was active at death. Localised patches of new bone formation, some of it compact and some more porous, was observed on the cranial diaphysis of a horse metapodial (Figure 9.85). The differing morphology of the new bone possibly indicating a condition that was either healing or had been

re-activated prior to death. The new bone, although only surviving in patches, was probably widespread across the distal cranial diaphysis.

a

b

Figure 9.85 Horse metapodial with localised periostosis on the distal cranial diaphysis (a), with a close-up view of one of the plaques of new bone (b) (Photo: Author)

The plaques of new bone recorded may be the result of systemic infection, trauma, neoplasia, metabolic/nutritional deficiency or be associated with osteomyelitis. However, with disarticulated and fragmented bones like these, it is impossible to ascertain a definite aetiology. Two of the sixteen cases of periostosis identified were located on the visceral surface of LTM rib fragments. The locations of these lesions suggest the presence of an active respiratory infection at death (Figure 9.86).

a b

Figure 9.86 Large terrestrial mammal (LTM) rib (a) with new bone formation on the visceral surface (b) (Photo: Author)

Periostosis was recorded on six mandibles (oral skeletal region), affecting sheep/goat, pig, LTM and MTM. These plaques of woven bone were located on the buccal surface, lingual surface and around the alveolus. These lesions may be associated with periodontal disease, infection or trauma.

The lesion types associated with non-specific bone lysis were as follows: pitting and porosity (33%), space-occupying lesion (25%), enlarged foramen (25%) and

porous, lytic lesions (17%) (Figure 9.87). The cranial, axial and appendicular skeleton was affected, with the greatest frequency associated with the axial region. When these two regions were compared using chi-square, a significant difference was identified at $\alpha = 0.05$ ($X^2 = 4.45$, $p = .0348$, $p < 0.05$, d.f. = 1), verifying this pattern in the data.

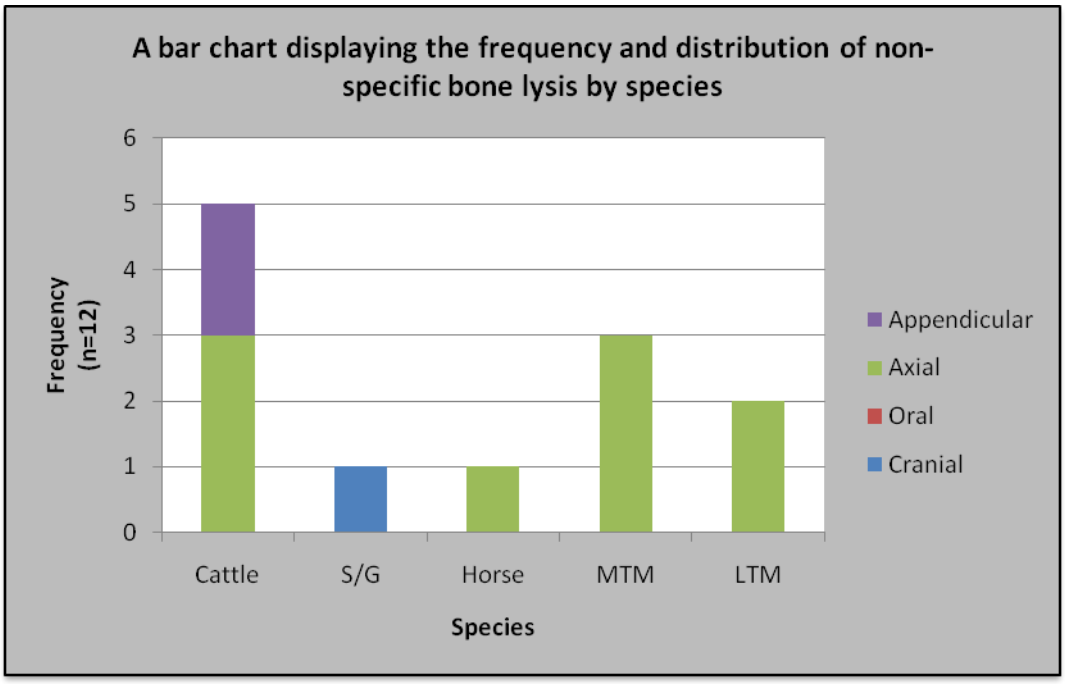


Figure 9.87 Non-specific bone lysis by skeletal region at Barton field

Pitting/porosity was the most frequent type of non-specific bone lysis recorded, representing 33% of the lesions. Three cases were observed, affecting a cattle metatarsal (Figure 9.88), a cattle axis and a LTM sacrum fragment. These isolated cases may be related to trauma, infection or arthropathy. They could also in some cases be age-related and associated with osteoporosis/osteopenia. Bone porosity within the vertebral foramen may be associated with infection of the

blood vessels or but may also represent a nutritional deficiency or metabolic disorder. Space-occupying lesions and enlarged foramina were joint second in frequency, combining to comprise 50% of the lesions recorded. Cattle, horse and MTM were affected (Figure 9.88). Two small space-occupying lesions were observed in a cattle thoracic vertebral plate, possibly representing either localised infection or subchondral cysts. Two space-occupying lesions were also identified within the vertebral foramen of two MTM lumbar vertebrae (these vertebrae were definitely not sheep/goat or pig). The lesions were purely destructive with no associated new bone formation, suggestive of infection. The enlarged foramina were observed in a cattle axis, distal cattle metatarsal and a horse lumbar vertebra. These could just be normal variation or a developmental anomaly; however, they could also represent the presence of infection associated with the blood vessels.

Figure 9.88 Abnormal pitting between the articulating facets of this proximal cattle metatarsal. Close-up view of the pitting (Photo: Author)

9.6.2 The Associated Bone Groups (ABGs)

Although it was reported that four sheep/goat skeletons were recovered from Iron Age pits (see Peck 2006: 164), these were unfortunately not located for recording by the present researcher. A number of articulated remains were identified, however, these were either definitely Romano-British in date (as in the case of two horse burials – see Hicklin 2006) or suspected of being so. The only two ABGs that may possibly have been Iron Age or Iron Age/Romano-British were a partial sheep skeleton and a near complete horse skeleton (Table 9.26).

Table 9.26 Barton Field: ABGs

Context Number	Age Estimation in months (epiphyseal fusion & tooth eruption)	Tooth Wear/Crown height (mandible wear score)	Sex Determination	Pathological?
BVI PIT V Partial sheep	(18-24) - (36)	-	-	N
A VI FII horse*	>60	-	M	Y

*sampled for aDNA

Palaeopathology

Of the two ABGs recorded, just the horse was pathological (Table 9.27). Little is known about the location of this horse ABG in relation to the site at Barton Field. It is not mentioned by Peck in his analysis (see Peck 2006). However, the remains recorded clearly belong to the same individual and were in a fair-good condition.

This horse was also sampled for aDNA analysis (section 9.7). The different types of lesion identified are presented in Figure 9.89. This information along with the suspected aetiologies is summarised below.

Table 9.27 Horse ABG: The frequency of lesion types

Horse	Frequency of Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
A VI FII*	1	2	-	6	-	5

*Sampled for aDNA

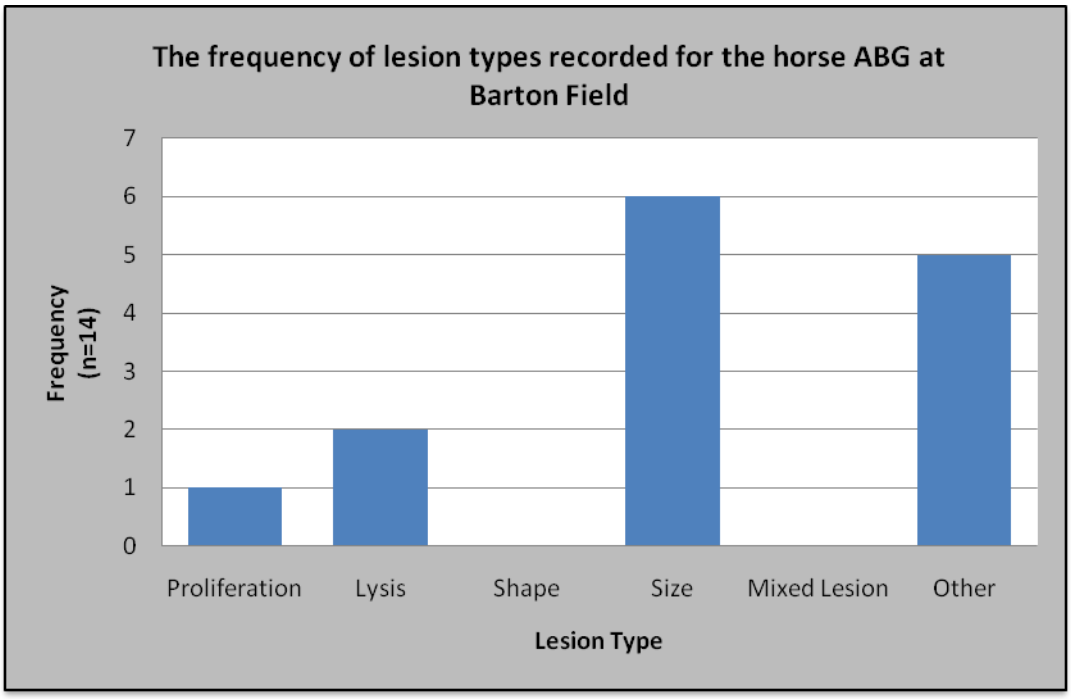
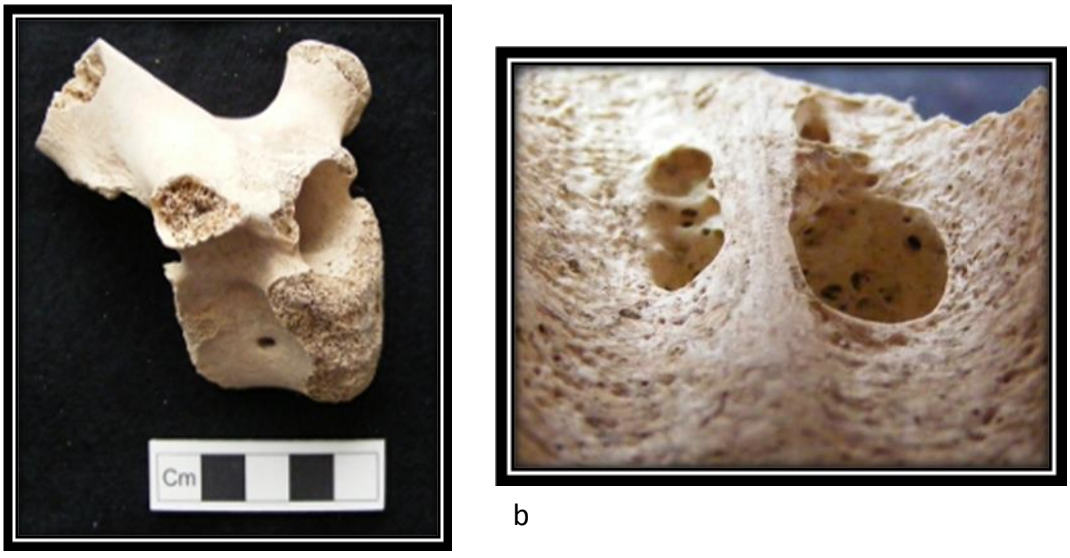


Figure 9.89 A VI FII: The frequency of lesion type

The two most frequent lesion types recorded were associated with bone size (43%) and the other category (36%). All of the pathological lesions were identified on the axial skeleton.

A VI FII

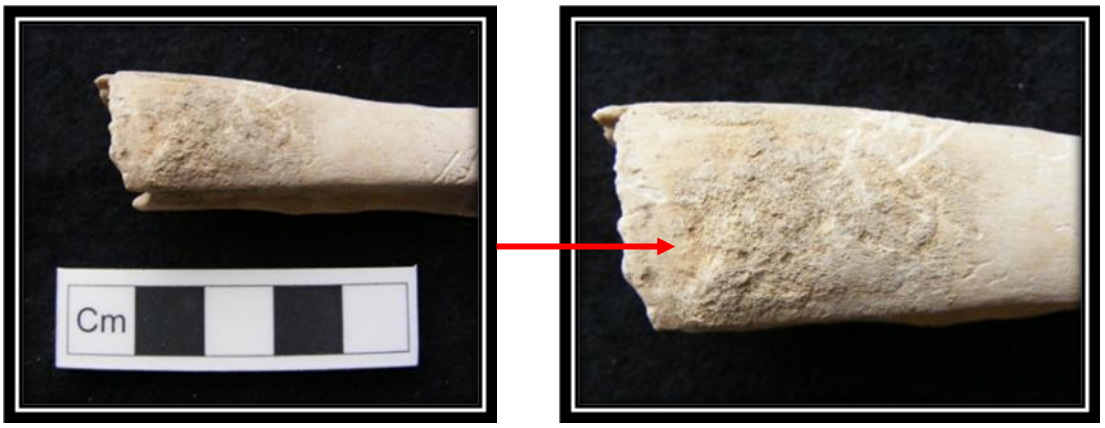
This male horse skeleton was aged at least 5 years at death; unfortunately, the crown heights of the teeth were not measured so cannot help to narrow the age further. The most frequent pathological condition recorded was enlarged foramen, identified in six thoracic vertebrae. The affected foramina were largely located on the lateral sides of the vertebral bodies, but one also exhibited enlarged foramina within the vertebral foramen (Figure 9.90).



a b

Figure 9.90 Horse thoracic vertebra with enlarged foramen on the lateral vertebral body (a). Enlarged foramen also visible within the vertebral foramen (b) (Photo: Author)

Porous, lytic lesions were also observed within the vertebral foramen of an axis and the transverse foramina of a cervical vertebra. The second most frequent lesion identified was associated with trauma. Five fragments of ossified costal cartilage possessed a series of microfractures. Lastly a single case of periostosis was noted on the visceral and lateral surface of a rib fragment (Figure 9.91). The new bone on the visceral surface appears to join with the new bone on the lateral surface, possibly indicating the spread of the original lesion.



a b

c

Figure 9.91 Horse rib with periostosis on the visceral and lateral surfaces. New woven bone formation on the visceral (a, b) and lateral surfaces of the horse rib (c). The arrow indicates the location of aDNA sampling (Photo: Author)

Summary and Differential Diagnosis

The presence of porous, lytic lesions and enlarged foramina when viewed within the same animal may indicate a related aetiology or several aetiologies. For example, the enlarged foramina may be related to infection or be associated with normal variation. However, the enlarged foramina illustrated in Figure 9.90, particularly when located within the vertebral foramen, do appear abnormal in size and shape as opposed to being the result of a non-metric trait or developmental anomaly. The porous, lytic lesions could be associated with a nutritional deficiency, metabolic disorder or possibly be associated with osteoporosis. The latter is improbable as the bones were not unusually light, (although this is not a specific indicator as taphonomy can also reduce bone density) and this type of porous, bone loss was not identified anywhere else in the skeleton. The location of woven bone on the visceral surface of the rib fragment spreading to involve the lateral surface would indicate the presence of an active respiratory infection at death. Therefore, the porous, lytic lesions, enlarged foramina and periostosis may collectively represent a systemic infection, of which the differential diagnoses would include both brucellosis and MTB complex. In order to try and establish a definitive aetiology for these lesions, the rib fragment was sampled for aDNA analysis (section 9.12).

Summary

The assemblage at Barton field totalled 6,292 fragments. Seventy-eight types of pathology were recorded on 69 bones, equating to just 1% of the entire assemblage. Sheep/goat and cattle were the most frequent species identified with an equal share of palaeopathological lesions (30% each). However, a chi-square test

demonstrated a significant difference between the frequencies of pathological bones for these two species when viewed in the context of their overall NISP counts. Non-specific bone proliferation and bone lysis lesions were identified, potentially indicating the presence of infection. A significant difference was identified in association with non-specific bone lysis, with sheep/goat displaying lower numbers of cases by comparison with cattle. Both non-specific bone proliferation and bone lysis were identified in the axial and appendicular regions, with the appendicular region favoured in bone proliferation lesions and the axial skeleton favoured in the lytic lesions. These patterns were both statistically significant at $\alpha = 0.05$. A rib associated with a horse ABG (A VI FII) with a periosteal rib lesion was sampled for aDNA analysis (section 9.12).

9.7 Danebury Hillfort, Nether Wallop, Hampshire

Danebury Hillfort was selected for three main reasons: it possesses the largest disarticulated Iron Age faunal assemblage in southern Britain; a total of seventy-four ABGs were recovered and the Hillfort represents a more densely occupied rural site with an estimated population of between 200-350 people (section 6.6.3). The faunal assemblage was recorded by Grant (Grant 1984a). A total of 276 pathological remains from the original assemblage were analysed in detail and reported on by Brothwell (1995). The greater majority of these were located (n=183) and re-recorded for the purposes of this research to fit into the analytical approach employed. As the bones analysed represent a small sample of a much larger assemblage, no statistical analyses were conducted. Therefore, it is unknown how representative the following analyses are in terms of the overall domestic animal herd population that served Danebury Hillfort. In addition to this sample of bones, a number of the recovered AGBs were also recorded.

9.7.1 The Disarticulated assemblage

The assemblage recovered during the first ten years of excavation totalled 138,528 fragments (Grant 1984a: table 61). The bone was recovered from occupation layers and features, including post-holes, pits and gullies (Grant 1984a). Basic quantification data (NISP) has been reproduced in Table 9.28 for the domestic species and illustrated in Figure 9.92 to provide an indication of species ratios over time at Danebury Hillfort.

Table 9.28 Danebury hillfort domestic species: Number of Identified Specimens (NISP) from all features (Data modified from Grant 1984a: table 61)

Domestic Species	Early		Middle		Late (a)		Late (b)		Undated		Total (TNF)	
SPECIES	**NISP**	**%NISP**	**NISP**	**%NISP**	**NISP**	**%NISP**	**NISP**	**%NISP**	**NISP**	**%NISP**	**NISP**	**%NISP**
Sheep/Goat	6633	58	3955	58	4609	59	17574	66	2043	55	34814	62
Cattle	2724	24	1130	17	1287	17	5536	21	740	20	11417	20
Pig	1796	16	1244	18	1108	14	2074	8	349	9	6571	12
Dog	137	1	147	2	502	6	467	2	468	13	1721	3
Horse	156	1	298	4	273	4	871	3	128	3	1726	3
Total No. Identified	**11446**	**-**	**6774**	**-**	**7779**	**-**	**26522**	**-**	**3728**	**-**	**56249**	**-**
Misc*	5902	-	3357	-	3764	-	12581	-	1347	-	26951	-
TNF (Domestic species + misc)	**17348**	**-**	**10131**	**-**	**11543**	**-**	**39103**	**-**	**5075**	**-**	**83200**	**-**
Unidentified	11439	-	6229	-	7064	-	25931	-	3628	-	54289	-

***Skull fragments, ribs, axial and abaxial phalanges and metapodials**

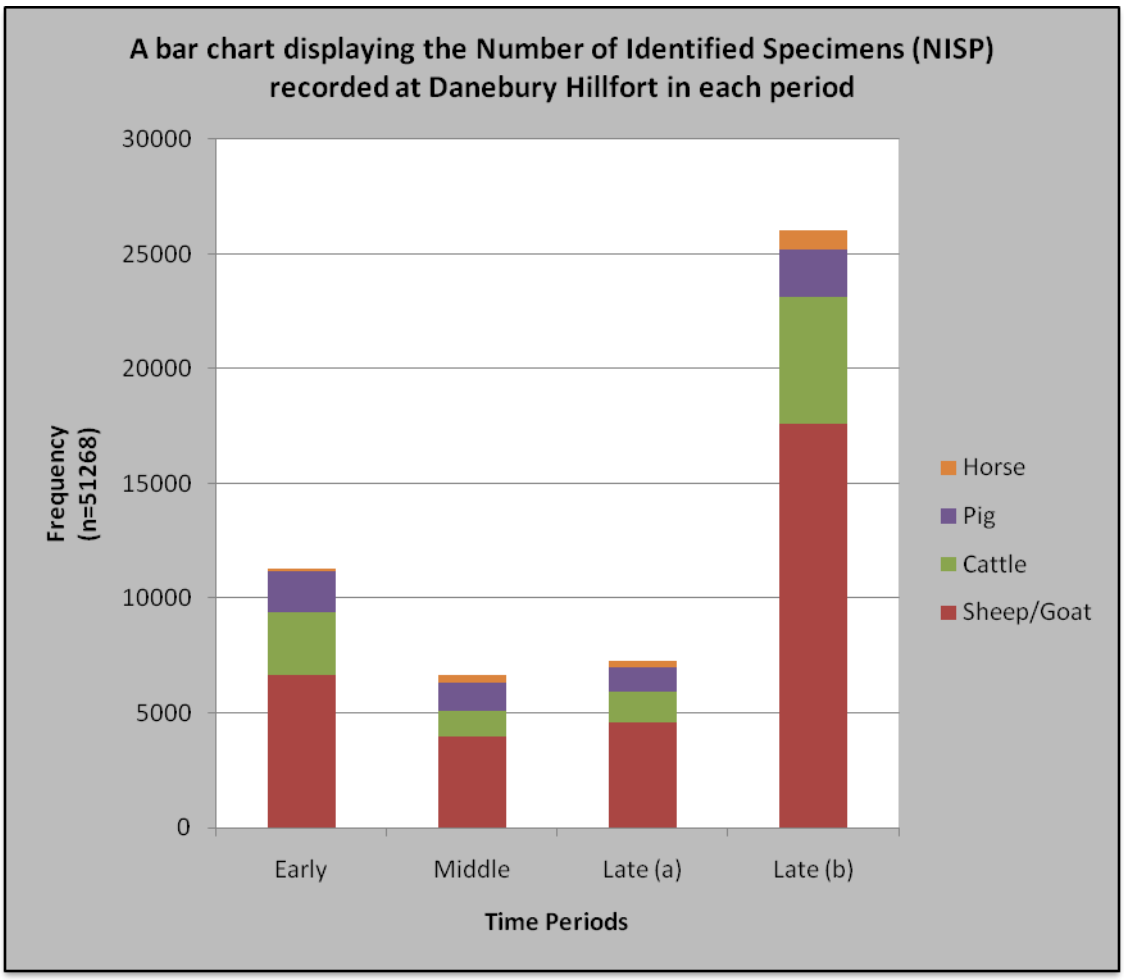


Figure 9.92 Number of Identified Specimens (just domestic species) recorded at Danebury Hillfort (Data from Grant 1984: table 61)

Palaeopathology

Three hundred and twenty-four types of pathology were recorded on a sample of 183 bones, equating to less than 1% of the entire assemblage. It is unknown whether the bones originally recorded by Brothwell (n=276) represent all the pathological remains observed at Danebury or are just a sample. The latter is assumed to be more likely in light of the assemblage size. As a part of the original analysis, Brothwell analysed the different pathological conditions identified by

phase allowing the observation of differences over the different phases at Danebury Hillfort (Brothwell 1995: 233). This has not been repeated here; the following presentation of the results is based upon the collective analysis of the pathological specimens. Of the species identified, sheep/goat possessed the most pathological lesions, comprising 37% of the sample recorded, followed by cattle (26%) and pig (15%) (Figure 9.93).

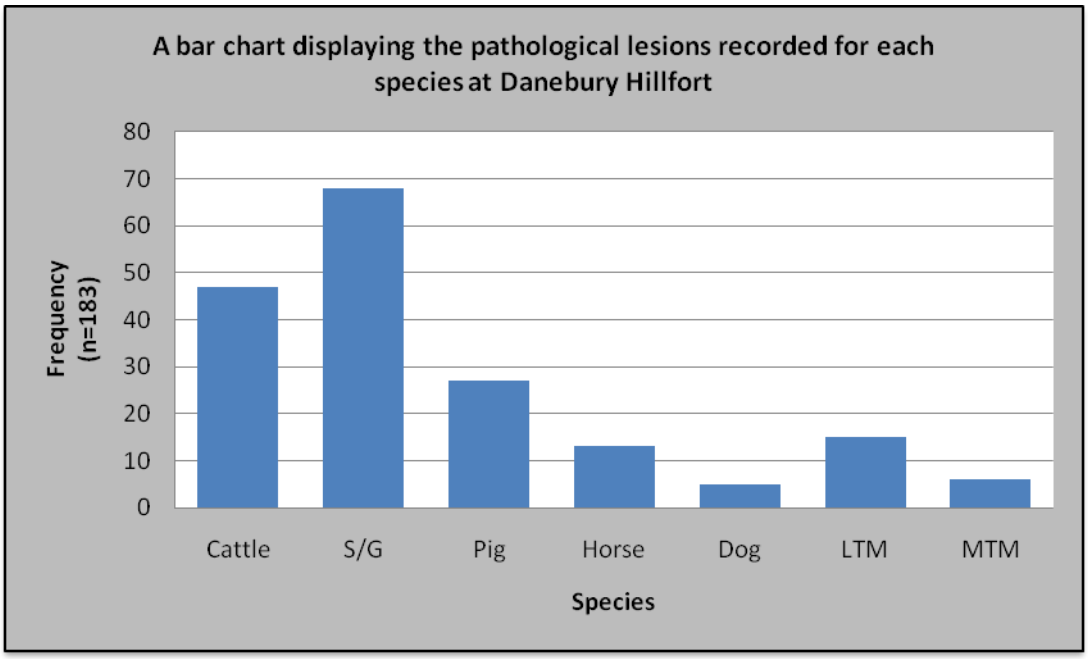


Figure 9.93 The frequency of pathological lesions recorded by species at Danebury Hillfort

A summary of palaeopathological lesion types

Table 9.29 and Figure 9.94 illustrate the frequency of pathological conditions by species for the extracted sample from Danebury Hillfort. Lesions recorded as 'other' represent the most frequent types recorded (31%), followed by abnormal bone formation (29%) and abnormal bone loss (23%). The 'other' category comprised the following lesion types: fractures (17%), malocclusion (17%), calculus (13%), tooth misalignment (12%), abnormal attrition (10%), eburnation (10%), ante-mortem tooth loss (7%), retained deciduous tooth roots (2%), absent cusps (2%), pulp cavity exposure (2%), hypercementosis of tooth roots (2%), congenital tooth absence (2%) malformed horn-core (1%), developmental fissure/crack (1%) and ventral margin disturbance (1%). Abnormal bone formation comprised: periostosis (34%), osteophyte formation (20%), ankylosis (19%), enthesophyte formation (12%), compact bone (nodule) (5%), exotoses (5%), syndesmophyte formation (3%) and other (abnormal bone formation, possibly developmental affecting a cattle caudal vertebra) (1%). Pitting/porosity dominate the abnormal bone lysis lesion type (45%), followed by alveolar bone resorption (30%), cortical clefts/fissures (possibly non-pathological) (10%), space-occupying lesions (8%), osteochondrosis manifesta (4%) and cortical perforation (1%). The remaining pathology types include abnormal bone shape (7%), several mixed lesions (6%) and abnormal bone size (5%). Abnormal bone shape included, deformed and dysplastic bones with no obvious fracture, asymmetry and extension of distal condyles (metapodia and phalanges), deformed horn-cores, characteristic horn-core 'thumb' prints and widening of the alveoli. Abnormal

bone size consisted of enlarged foramina and general areas of swelling affecting the long bone diaphysis (possible cases of osteitis). The combined cases included fracture with callus formation, lesions with evidence for both bone formation and bone lysis, for example, osteomyelitis, and ante-mortem tooth loss with remodelling.

Table 9.29 Danebury Hillfort: Summary of pathological lesion types by species

Species Affected	**Lesion Type**					
	Proliferation	**Lysis**	**Shape**	**Size**	**Combination**	**Other**
Cattle	28	14	5	3	1	11
Sheep/Goat	29	41	12	11	5	70
Horse	14	9	-	-	-	3
Pig	11	6	4	1	5	7
Dog	2	-	-	-	2	4
LTM	8	2	1	1	4	3
MTM	2	1	-	-	3	1
TOTAL No.	**94**	**73**	**22**	**16**	**20**	**99**
TOTAL %	**29**	**23**	**7**	**5**	**6**	**31**

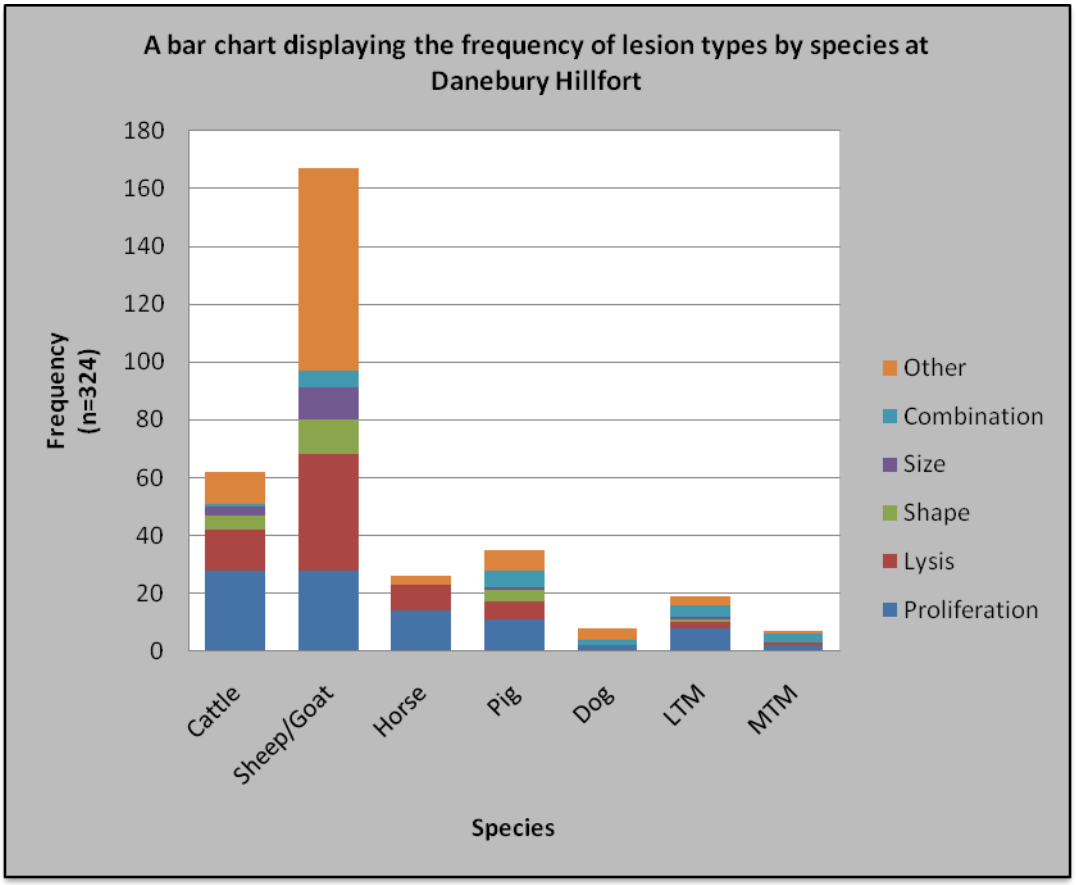


Figure 9.94 The frequency of lesion types by species at Danebury Hillfort

A summary of palaeopathological lesion characteristics: suspected aetiologies

Table 9.30 and Figure 9.95 illustrate the frequency of pathological conditions recorded by species at Danebury Hillfort. Trauma was the most frequent category (33%), followed by oral pathology (21%), arthropathy (17%), non-specific bone proliferation (11%), other (8%), non-specific bone lysis (3%), congenital (3%) and mixed lesions (3%).

Table 9.30 Danebury Hillfort: Summary of aetiologies by species

Species Affected	General Aetiology Categories							
	Oral	Trauma	Arthropathy	Congenital	Infection?		Mixed lesions	Other
					Non-specific bone proliferation	Non-specific bone lysis		
Cattle	2	15	17	2	6	3	-	9
Sheep/Goat	37	17	9	4	10	-	2	4
Horse	2	3	3	-	1	-	4	2
Pig	2	16	1	1	5	2	1	1
Dog	2	4	-	-	-	-	-	-
LTM	-	11	3	-	1	2	-	-
MTM	-	4	2	-	-	-	-	-
TOTAL No.	**45**	**70**	**35**	**7**	**23**	**7**	**7**	**16**
TOTAL %	**21**	**33**	**17**	**3**	**11**	**3**	**3**	**8**

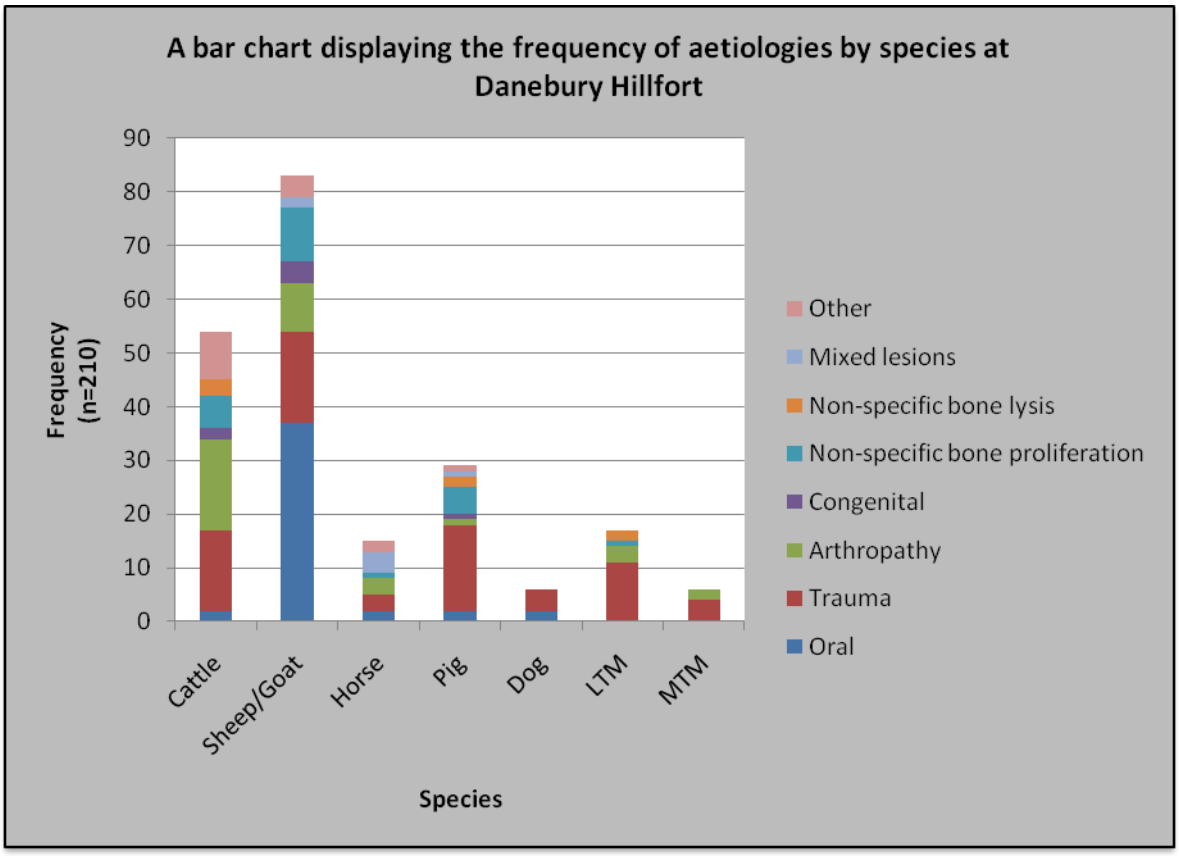


Figure 9.95 The frequency of aetiologies recorded by species at Danebury Hillfort

Evidence for Possible Infection and Differential Diagnosis

A number of those pathological lesions recorded may potentially indicate the presence of infection. These include those categorised as non-specific bone proliferation and non-specific bone lysis, in addition to some of the mixed lesion cases. Non-specific bone proliferation totalled 11% of the suspected aetiologies. All of these cases were identified as periostosis and were identified most

predominantly on the mandible and maxilla (oral region) and the appendicular skeleton (Figure 9.96).

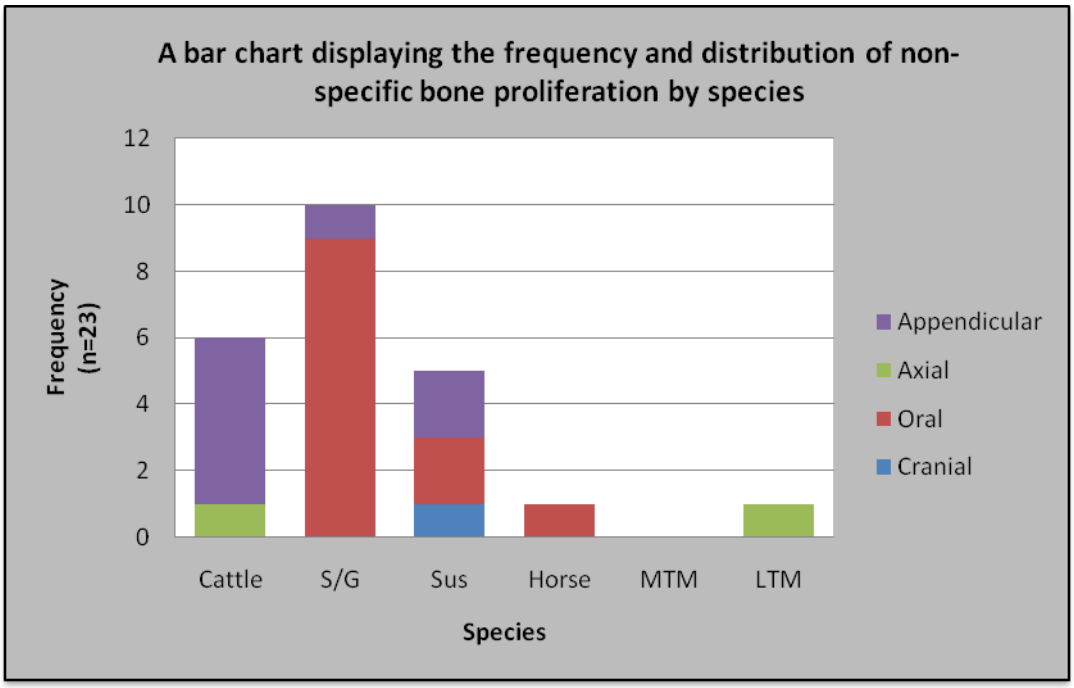


Figure 9.96 Non-specific bone proliferation by skeletal region at Danebury Hillfort

Eight cases of periostosis were observed in the appendicular skeleton, primarily affecting the long bone diaphyses of cattle and sheep/goat, with a single example affecting a pig scapula blade. The periostosis largely consisted of localised plaques of compact new bone formation suggesting a healed condition. A cattle metacarpal possessed several substantial plaques of compact new bone formation located diffusely on the cranial diaphysis (Figure 9.97). There was also expansion of the cortical bone on the cranial side of the diaphysis evident in the cross-section of the bone. The proximal epiphysis and caudal face of the

diaphysis were seemingly unaffected. The cranial patches of new bone may well have originally joined together covering the vast majority of the cranial diaphysis. A substantial plaque of new bone such as this may represent the remains of an involucrum and a resolved osteomyelitis. However, if this were an involucrum, one would expect the original cortical bone to be less dense and partially destroyed which it is not. There may have been a fracture perhaps in the distal region of the bone. Trauma appears a more likely aetiology as opposed to infection in this instance. The axial skeleton was affected in two cases, a cattle and LTM pelvis fragment with localised periostosis identified on the pubis and ischium, respectively. These examples of reactive bone formation may be the result of several possible aetiologies, including non-specific infection, trauma, neoplasia or metabolic/nutritional deficiency. Although it is difficult to be more specific when dealing with disarticulated and fragmented remains, the localised nature and morphology of a number of these cases would point towards either resolved trauma or resolved infection. Eleven cases of periostosis were also recorded on both sheep/goat and pig mandibles, with a single example observed on a horse maxilla. In sheep/goat and pig, the periostosis comprised plaques of woven bone located on the buccal surface, lingual surface and alveolus. In the horse maxilla fragment, spicules of new bone were observed on the palate, surrounding the lingual side of the pre-molar teeth. These lesions may be associated with periodontal disease, localised infection or localised trauma. A single case of woven bone was identified on a fragment of pig skull (lacrimal region). Brothwell indicated that the latter may be related to malnutrition or be

stress-related (Brothwell 1995: 231), although it may also be related to localised trauma. Pitting was also noted on another fragment of the same skull.

Figure 9.97 Cattle metacarpal with substantial plaques of compact new bone formation on the cranial diaphysis. When viewed in cross-section the cortical bone is also thicker on the cranial side. The original line of the cortex can no longer be discerned illustrating the well-healed nature of this pathological condition (Photo: Author)

Non-specific bone lysis comprised 3% of the suspected aetiologies. A total of ten non-specific bone lysis lesions not obviously associated with trauma or arthropathy were recorded on seven bones. These may potentially indicate infection and included the following lesion types: pitting and porosity (44%),

space-occupying lesions (33%) and enlarged foramina (22%) (Figure 9.98). The axial (n=4), appendicular (n=2) and cranial (n=1) regions were affected.

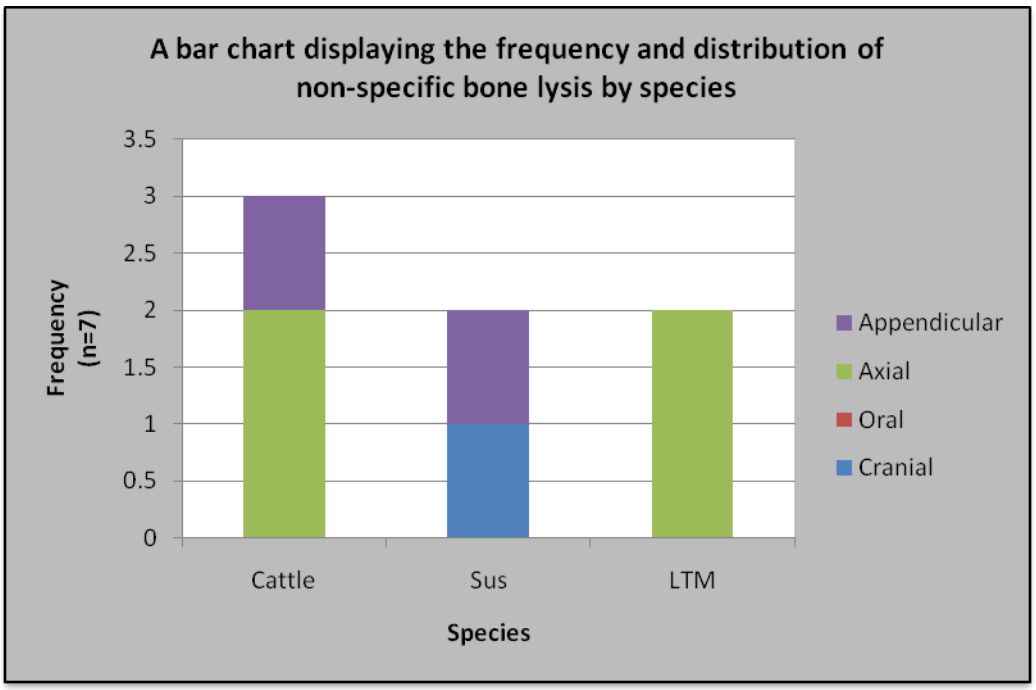


Figure 9.98 Non-specific bone lysis by skeletal region at Danebury Hillfort

Pitting and porosity was the most frequent type of non-specific bone lysis recorded (44%). Pig was affected in two cases; slight pitting was noted on a cranial fragment and on the diaphysis of a first phalanx. The latter also possessing a small space-occupying lesion. Pitting on the skull fragment (parietal bone) was also accompanied by periostosis on another region of the same cranium. These conditions may or may not share a common aetiology, so were recorded separately as opposed to as a mixed lesion case. As stated above, Brothwell suggested malnutrition or stress as potential causes (Brothwell 1995: 231); however, trauma and infection would also need consideration for

differential diagnosis. The pitting and space-occupying lesion affecting the diaphysis of the phalanx may be associated with localised trauma or infection. Pitting was also noted on a cattle metatarsal and a LTM lumbar vertebra. The proximal articular surface of the cattle metatarsal was more pitted than normal but there were no other signs of arthropathy, for example, joint contour change, osteochondrosis, eburnation, osteophyte formation etc. Therefore, this could just relate to normal variation or be indicative of early stage infection or early stage arthropathy. The pitting in the LTM lumbar vertebra was also accompanied by some porosity, multiple space-occupying lesions and eburnation (Figure 9.99). The caudal epiphysis of this lumbar vertebra has been perforated and destroyed apart from a small region on the lateral border that has been spared but displays eburnation. The radiograph illustrates the depth of the cavities and the sclerotic response of the bone. The lesions do not appear to penetrate too deeply into the vertebral body and the cranial epiphysis appears unaffected. The cavities, although irregular in shape and size are remodelled with smooth margins. There is no enlargement of the vertebral foramina and no obvious bone resorption affecting the dorsal surface of the vertebral body as observed in other vertebrae from both Wetwang Slack and Tarrant Hinton. The morphology of the lesions affecting this vertebral body, in association with the eburnation, would suggest an infectious arthropathy, with MTB Complex and brucellosis amongst the differential diagnoses. Although, it is possible, that infection was a later, separate occurrence. This bone was sampled for aDNA analysis (section 9.12)

a

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b

c

d

e

Figure 9.99
LTM lumbar vertebra (a) displaying destruction of the vertebral plate (c, d) with marked sclerosis visible on the x-ray (b). Microporosity (d) is also visible (e) (Photo: Author, x-ray: Dr. J. Buckberry).

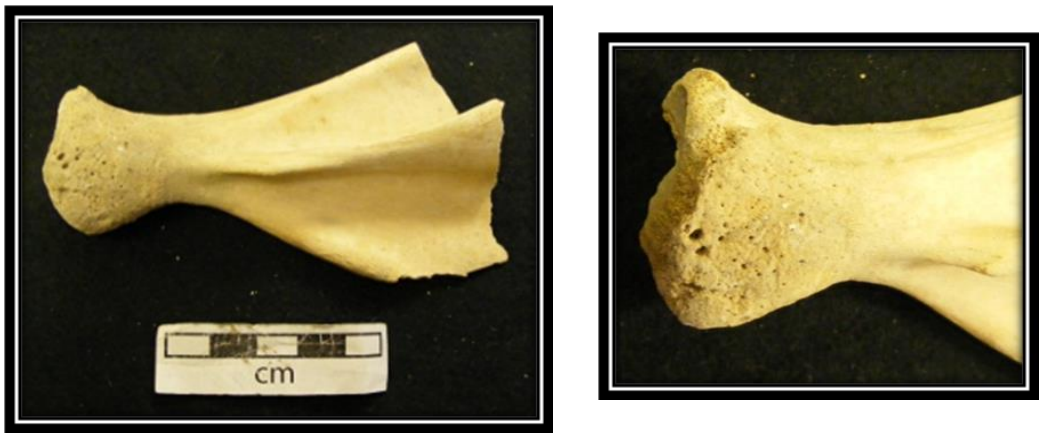
A cattle caudal vertebra possessed a ‘U’ shaped space-occupying lesion in the cranial epiphysis in addition to enlarged foramina. This lesion may be associated with localised trauma, however, there was no reactive bone formation but margins were smooth. The enlarged foramina may be associated with normal variation, but may also point towards the presence of infection. Two other examples were observed; one affecting another cattle caudal vertebra and one affecting a LTM lumbar vertebra and measuring 4mm in length (Figure 9.100).

a b

Figure 9.100 LTM lumbar vertebra with an enlarged foramen visible on the lateral vertebral body (a). Close-up view of enlarged foramen with smooth edges (b) (Photo: Author)

Seven bones were identified with multiple mixed lesions. A sheep/goat skull fragment possessed a lytic lesion measuring 3-4mm in length and positioned just over 1cm medial to the orbit. Brothwell describes this as a ‘sinus aperture’ (Brothwell 1995: 210). The margins of the lesion are remodelled and there is also

new bone formation and pitting surrounding it as well as endocranially. This potentially represents a chronic sinus infection, with a cloaca. New bone formation and pitting were identified on a horse radius, located on the proximal epiphysis at the point where the ulna articulates. This may be associated with minor trauma, arthropathy or inflammation (infectious arthropathy). A sheep/goat second phalanx possessed new bone formation in addition to a space-occupying lesion affecting the diaphysis. This could be associated with either trauma and/or infection. The remaining four cases all strongly suggest an infectious aetiology. A pig scapula displays swelling, pitting and porosity in the neck region surrounding the glenoid fossa (Figure 9.101). This lesion is similar to that displayed in the modern pig skeleton from Chester (see section 9.4.1). The modern example also possesses a large space-occupying lesion, but there is swelling in the same region of the neck. The example from Danebury may, therefore, represent osteitis or an early stage osteomyelitis with no cloaca.



a b

Figure 9.101 Pig scapula displaying swelling, pitting and porosity in the neck region (a). Close-up view of the swelling (b). (Photo: Author)

A horse femur was identified as possessing both proliferative and lytic lesions affecting the neck region of the femoral head (Figure 9.102). There is a space-occupying lesion measuring c. 2cm x 1cm on the medial side of the femoral head exposing the trabecular bone beneath. Although the lesion is irregular in shape, it appears to have remodelled with smooth margins. In addition to this, there is compact new bone formation on the neck of the femoral head; this is bulbous and irregular in form. Pitting and porosity is also evident. There is more substantial bone loss visible distal to the femoral head (Figure 9.102, view b). However, on closer inspection this may actually be taphonomic. There is some slight roughening of the femoral head, which may indicate arthropathy, but there is no eburnation. This combination of lesions is suggestive of an infectious arthropathy affecting the hip joint (Brothwell 1995: 222).

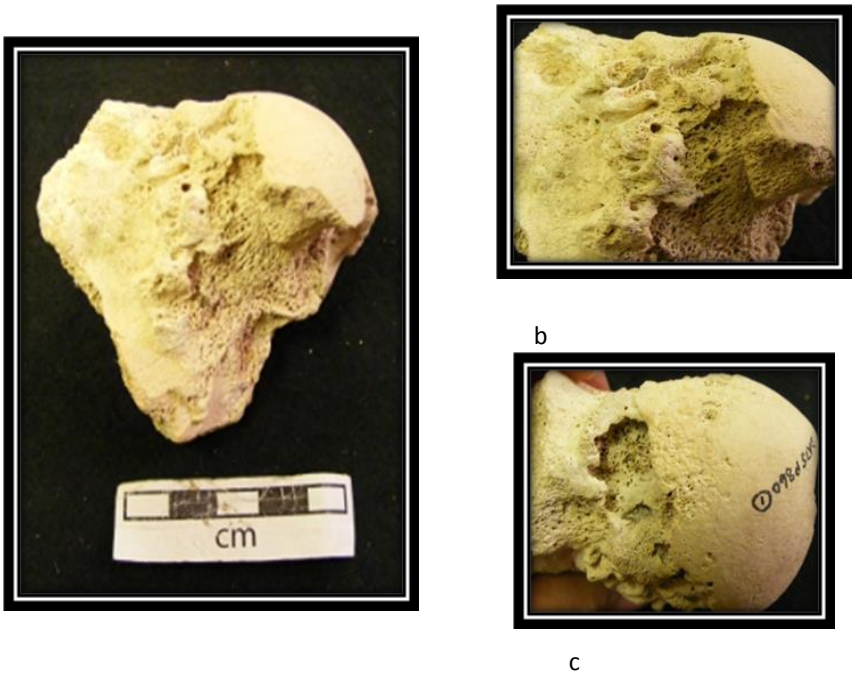


Figure 9.102 Horse femur with mixed proliferative and lytic lesions. Space-occupying lesions expose the trabecular bone beneath (a,c), in addition to irregular compact new bone formation/exotoses (b)

The last two cases involve the occipital region of a horse cranium and a horse atlas. These two bones are contiguous and belonged to the same animal. An enthesophyte is located on the occipital bone and also on the dorsal surface of the atlas (Figure 9.103). These types of lesions have been associated with trauma and infection, involving the nuchal ligament and could represent a case of poll evil (section 4.2.1). Infection is implicated in this case as the internal aspect of the occipital region of the cranium was also pitted (see Figure 9.103, view e), so this was a condition that had instigated both a proliferative and destructive response. Poll evil has been associated with brucellosis, actinomycosis and non-specific infection (section 4.2.1). These two bones were sampled for aDNA analysis (section 9.12).

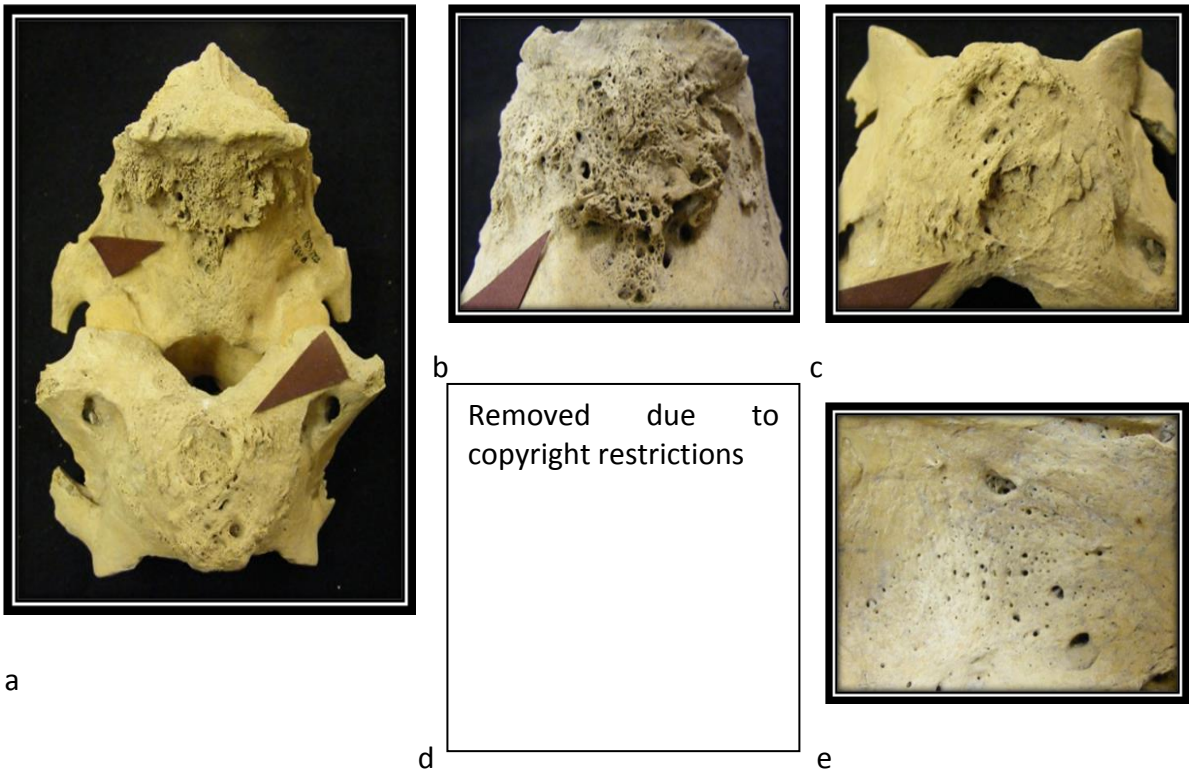


Figure 9.103 Occipital region of a horse skull and a horse atlas (a) displaying enthesophytes on both the occipital bone and dorsal atlas (b, c, d). Pitting is also visible on the internal aspect of the occipital bone (e) (Photo: Author, X-ray: Dr. Jo. Buckberry)

9.7.2 The Associated Bone Groups (ABGs)

A total of 74 ABGs (cattle, sheep/goat, pig, horse, dog and cat), 25 articulated limbs (cattle, sheep, pig and horse), 151 skulls (cattle, sheep/goat, pig, horse and dog) and 32 mandibles (horse) from all phases were excavated at Danebury Hillfort (Grant 1984a: 533-43). These 'special animal deposits' were recovered from 161 pits, representing 18% of the total number of pits excavated (n=891). Fifty-seven of these pits (35%) contained animal burials (ABGs) (Table 9.31) (Grant 1984a: Table 92), and it is these that were targeted for analysis.

The ABGs were organised into categories based upon their level of completeness:

a) Complete, articulated animal
b) Complete or almost complete (not necessarily fully articulated)
c) Partial burial
d) Possible burial

(Information taken from Grant 1984a: Microfiche 17: E3-9)

Based upon this information, only those ABGs categorised as a, b or c were targeted for analysis. Unfortunately, only 36% of the ABGs (n=27) were located by the present researcher.

Table 9.31 Animal burials (ABGs) excavated at Danebury Hillfort by species, age range and phase (Data taken from Grant 1984: Table 88)

Phase	Cattle		Sheep*		Pig		Horse		Dog		Cat		Total
	MWS 1-5	MWS 6+	MWS 1-5	MWS 6+	MWS 1-5	MWS 6+	Y	J/M	Y	J/M	Y	J/M	
Early	5	3	4	2	2	2	0	0	1	0	0	0	**19**
Total	*8*		*6*		*4*		*0*		*1*		*0*		**(26%)**
Middle	2	0	2	2	7	4	0	1	0	2	1	0	**21**
Total	*2*		*4*		*11*		*1*		*2*		*1*		**(27%)**
Late (a)	2	0	3	0	2	2	0	1	0	3	0	0	**13**
Total	*2*		*3*		*4*		*1*		*3*		*0*		**(18%)**
Late (b)	2	0	8	5	3	0	0	1	1	1	0	0	**21**
Total	*2*		*13*		*3*		*1*		*2*		*0*		**(30%)**
Grand Total	**11**	**3**	**17**	**9**	**14**	**8**	**0**	**3**	**2**	**6**	**1**	**0**	**74**
	14 (19%)		**26 (35%)**		**22 (30%)**		**3 (4%)**		**8 (11%)**		**1 (1%)**		

*Includes 1 x Goat

MWS (Mandible Wear Score)
Y – Young
J/M – Juvenile/Mature

Cattle ABGs

A total of nine cattle ABGs were recorded (Table 9.32). Five of these were not listed in the report, so unfortunately cannot be phased. The vast majority of these were juvenile, with just three older individuals represented. The oldest examples were a minimum of 3 ½ - 4 years of age at death. None could be reliably sexed.

Table 9.32 Cattle ABGs recorded at Danebury Hillfort: Age-at-death and sex determination

Phase	Context Number	Age Estimation in months (epiphyseal fusion & tooth eruption)	Tooth Wear (mandible wear score)	Sex Determination	Pathological
Early (470 - 310 BC)	DA 78 P1028 LAYER 4 (I)	<7-10	-	-	N
	DA 78 P1028 LAYER 4 (II)	<7-10	-	-	N
	DA 78 P1028 LAYER 3 (III)	<36-42	-	-	N
	DA 76 P909 LAYER 1	(7-10) – (12-18)	23-27	-	Y
Not listed in report (Phase unknown)	DA 83 P1987 LAYER 2	<7-10	-	-	N
	DA 82 P1996 LAYER 7 (BOS X)	>42-48	-	-	Y
	DA 82 P1996 LAYER 7 (BOS Y) (I)	(18-24) - <(36-42)	45	-	Y
	DA 82 P1996 LAYER 7 (BOS Y) (II)	(7-10) - <(12-18)	8	-	N
	DA 82 P1996 LAYER 7 (BOS Z)	>42-48	-	-	Y

Palaeopathology

Four of the nine cattle ABGs (44%) were pathological (Table 9.33). The different types of lesion identified and their distribution throughout the skeletons are presented in Figures 9.104 & 9.105. There was a significant difference in the skeletal distribution of pathological lesions throughout the skeleton at $\alpha = 0.05$ ($X^2 = 50.0$, $p = .0000$, $p < 0.05$, d.f. = 3). This indicates that the distribution is unlikely to be due to chance.

Table 9.33 The frequency of lesion types recorded for each cattle ABG

Cattle	**Frequency of Lesion Type**					
	Proliferation	**Lysis**	**Shape**	**Size**	**Mixed Lesion**	**Other**
DA 76 P909 LAYER 1	2	17	-	1	-	-
DA 82 P1996 LAYER 7 (BOS X)	1	-	-	3	-	1
DA 82 P1996 LAYER 7 (BOS Y) (I)	3	4	3	4	-	-
DA 82 P1996 LAYER 7 (BOS Z)	-	3	1	2	-	5

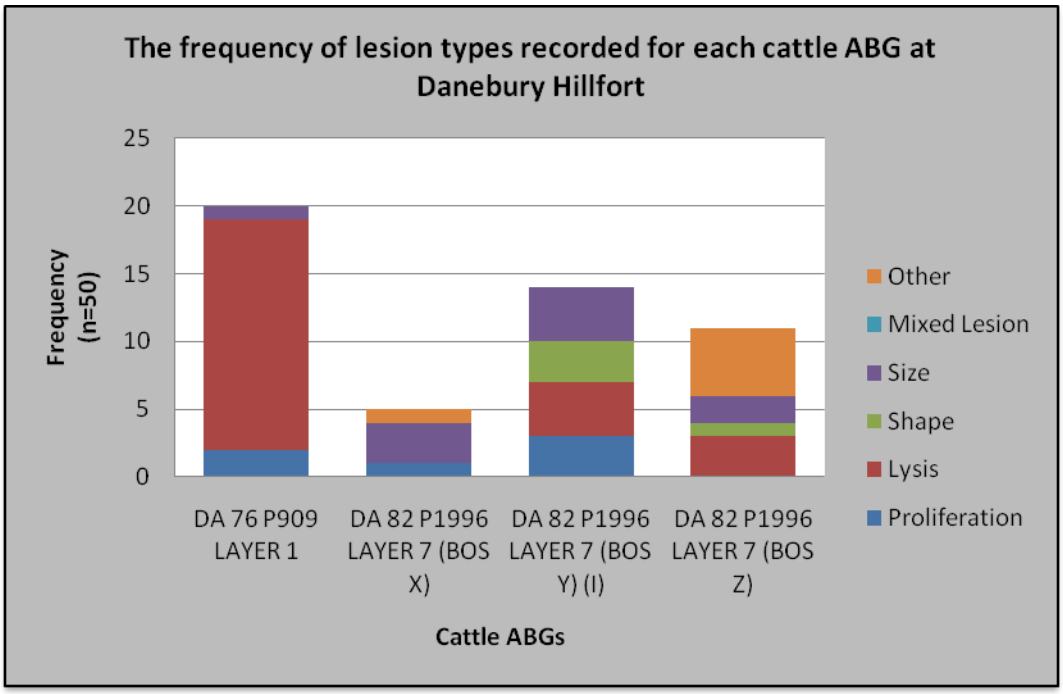


Figure 9.104 Cattle ABGs: The frequency of lesion types

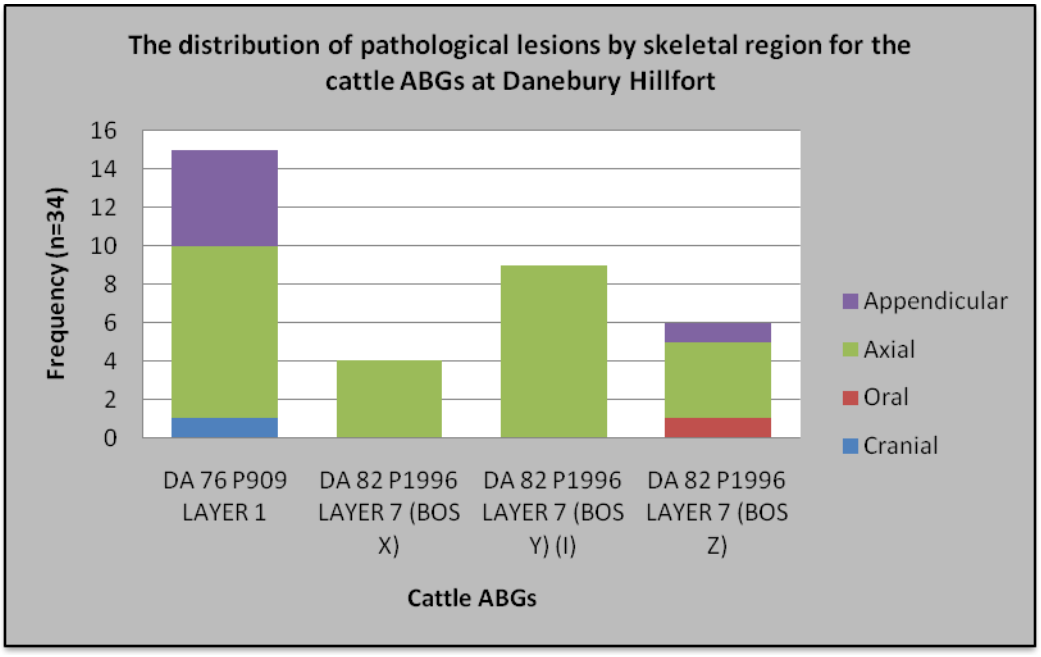


Figure 9.105 Cattle ABGs: The distribution of lesions by skeletal region

DA P909 LAYER 1

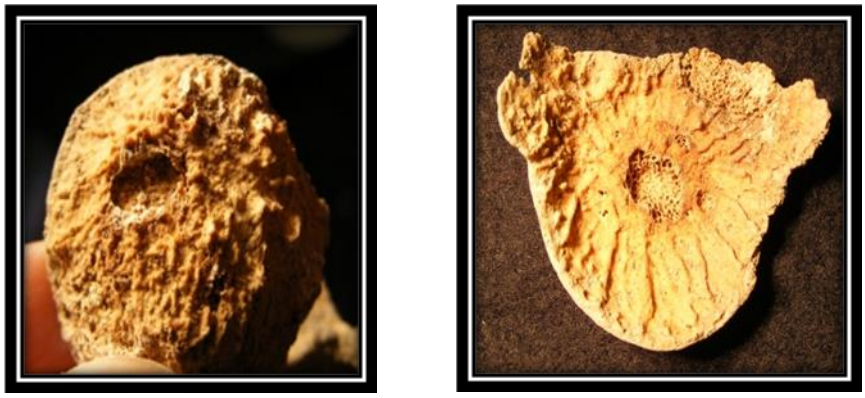
This juvenile cattle skeleton was aged between 7-10 months and 1-1 ½ years at death. The skeleton was partially articulated and located in a pit in association with a number of chalk rocks (Grant 1984: 536). The condition of the bone was generally fair, although some were very fragile and as a result had suffered taphonomic damage. Twenty instances of pathology were recorded, of which 85% (n=17) were associated with abnormal bone lysis. The majority of lesions were located in the axial skeleton (60%), followed by the appendicular skeleton (33%) (Figure 9.106). Thirteen lesion types were recorded in the axial skeleton, specifically affecting the vertebral column. The majority of these were identified as abnormal bone lysis, comprising space-occupying lesions. Abnormal bone proliferation (periostosis) and abnormal size (enlarged foramen) were also identified. The space-occupying lesions were identified in the axis, cervical vertebrae (C2 and C4) and some fragmented vertebral bodies and unfused epiphyses. The lesions were destructive with irregular edges. However, in some instances, the interior of the lytic lesions appeared remodelled with smooth margins (Figure 9.107).

a

b

Figure 9.106 Axis vertebra (a) with space-occupying lesion within the vertebral foramen (b) (Photo: Author)

A number of loose unfused vertebral epiphyses displayed shallow, non-perforating space-occupying lesions (Figure 9.107). In some cases, these were mirrored by similar lesions on the vertebral bodies. These lesions did not completely perforate the epiphyses, but some possessed smooth, regular margins. In addition to these, a single case of periostosis was observed on a vertebral transverse process (Figure X) and an enlarged foramen was identified on a caudal vertebra.



a b

Figure 9.107 Vertebral epiphyses with shallow, non-perforating space-occupying lesions (a, b) (Photo: Author)

Five cases of bone lysis were also recorded in the appendicular skeleton, affecting all four metapodia and a navicular cuboid. The lesions affected the joint surfaces and appeared as irregular clefts and fissures, not too dissimilar from the lytic lesions associated with osteochondrosis. However, these examples may represent non-pathological cortical defects. New bone formation and pitting was also noted on the occipital region of the skull, potentially representing the beginnings of an enthesophyte which may suggest either trauma or infection involving the nuchal ligament (see section 4.2.1).

Summary and Differential Diagnosis

The space-occupying lesions affecting the vertebrae were extremely destructive with no directly associated bone formation. However, the fact that they were widespread would suggest the presence of a systemic infection, especially with the addition of periostosis on the transverse process and the possible enthesophyte on the occipital bone. A number of the lesions appeared remodelled internally, with the sharp edges, possibly a combination of post-excavation damage and fragile bone. The multiple space-occupying lesions affecting the vertebral epiphyses and bodies would also suggest the presence of systemic infection. An alternative would be echinococcosis, a parasitic disease that can affect the vertebrae and result in the development of multiple cysts causing bone lysis (section 4.3.1). However, this disease also affects the posterior parts of the vertebrae and no lesions were identified on the neural arch. The fissures and clefts identified in the appendicular skeleton are unlikely to be associated with joint stress in an animal of this age. They are more likely to reflect a developmental problem with the cortical bone or cartilage.

The remaining ABGs

The remaining three cattle ABGs were more mature, with two at least 3 ½ - 4 years of age at death. Unfortunately, all three were not listed in the report so cannot be accurately phased. Enlarged foramina were observed in the vertebrae of all three, possibly representing infection or maybe just reflecting normal variation. However, the most striking palaeopathological abnormalities were observed in the vertebral

column of DA 82 P1996 LAYER 7 (BOS Y) (I). This ABG warrants a brief description as it may shed some light on the reason this particular animal came to be deposited in a complete state. This was the youngest of the three older ABGs; at least 1 ½/2 years – 3 years at death. Marked asymmetry was noted in the axis and cervical vertebrae, in addition to degenerative change affecting the articular facets of the affected vertebrae (Figure 9.108). This type of asymmetry affecting the cervical vertebrae is similar to that seen in horses suffering from cervical vertebral stenotic myelopathy, colloquially termed 'wobbler'. This condition can lead to spinal cord compression and ataxia (Palmer 1993: 48). This is not a condition that is described in relation to cattle but in horses, it is non-progressive, however, the symptoms may be exacerbated through strenuous activity or trauma (Palmer 1993: 48). The cause of this type of instability in the cervical region is uncertain, although a combination of genetic factors has been suggested, as well as rapid growth (Palmer 1993: 48). The asymmetry in this individual may well be associated with a similar condition; it could also be the result of congenital malformation or trauma at a young age. This abnormality may not have resulted in death; there was also evidence for possible infection with the presence of enlarged foramina in the vertebrae, as well as pitting and periostosis on the sternum. However, there is the possibility that compression of the spinal cord led to eventual ataxia and uncoordinated movement resulting in slaughter.

Figure 9.108 Contiguous atlas, axis, C1 and C2 displaying marked asymmetry possibly associated with vertebral stenotic myelopathy (Photo: Author)

Sheep/Goat ABGs

Six sheep and one goat ABG were recorded (Table 9.34). All but one was listed in the report. Of the six sheep, four were juvenile and two adult. The oldest examples were a minimum of 4-5 years of age at death and were female. One goat was recorded, a possible female aged between c. 3-7 years at death.

Table 9.34 Sheep/Goat ABGs recorded at Danebury Hillfort: Age-at-death and sex determination

Phase	Context Number	Age Estimation in months (epiphyseal fusion & tooth eruption)	Tooth Wear (mandible wear score)	Sex Determination	Pathological
Early (470 - 310 BC)	DA 73 P455*	33-84	47	F?	Y
Late (b) (50 BC – AD 40)	DA 71 P92 LAYER 5	<6-8	13-21	-	N
	DA 72 P120 LAYER 6	3-10	-	-	Y
	DA 72 P365 LAYER 5	6-8	7-8	-	N
	DA 72 P365 LAYER 6	6-10	-	-	Y
	DA 73 P475 LAYER 4	>48-60	33	F	Y
Not on fiche	DA 83 P2273	>48-60	-	F	Y

*Goat

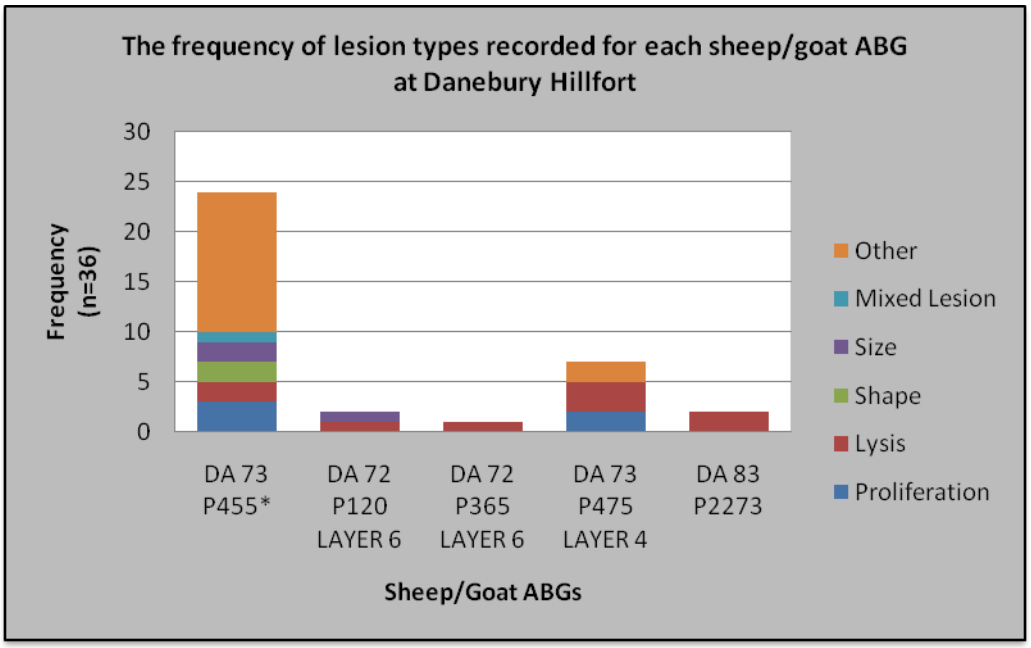
Palaeopathology

Five of the seven sheep/goat ABGs (86%) were pathological (Table 9.35). One definite goat was identified. The skeletons were all in a fair-good condition; three were partially complete and two complete. The different types of lesion identified and their distribution in the skeletons are presented in Figures 9.109 & 9.110. There was a significant difference in the skeletal distribution of pathological lesions throughout the skeleton at $\alpha = 0.05$ ($X^2 = 11.95$, $p = .0075$, $p < 0.05$, d.f. = 3). This indicates that the distribution is unlikely to be due to chance.

Table 9.35 The frequency of lesion types recorded for each sheep/goat ABG

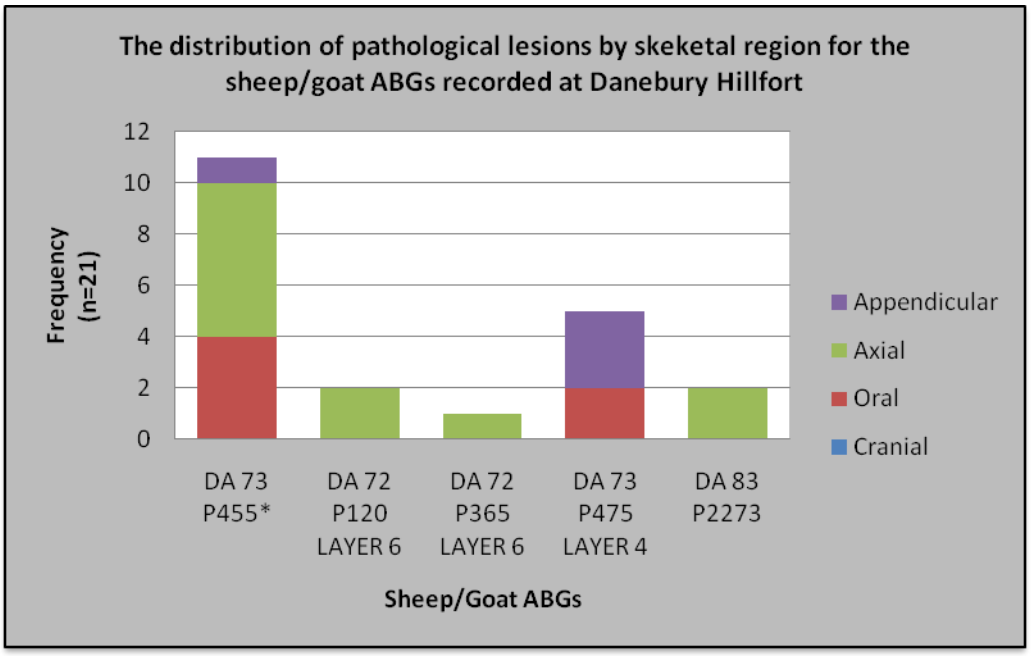
Sheep/Goat	Frequency of Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
DA 73 P455*	3	2	2	2	1	14
DA 72 P120 LAYER 6	-	1	1	-	-	-
DA 72 P365 LAYER 6	-	1	-	-	-	-
DA 73 P475 LAYER 4	2	3	-	-	-	2
DA 83 P2273	-	2	-	-	-	-

*Goat



*Goat

Figure 9.109 Sheep/Goat ABGs: The frequency of lesion types



*Goat

Figure 9.110 Sheep/Goat ABGs: The distribution of lesions by skeletal region

The Sheep/Goat ABGs

Four of the five sheep/goat ABGs possessed interesting lesions associated with a possible infectious aetiology. Sheep/goat ABG DA 73 P475 possessed lesions associated with arthropathy and periodontal disease, so is not presented in detail here. Lesions recorded as 'other' were the most frequent lesion type recorded (44%), followed by bone lysis (25%). Over half of the lesions recorded (52%) were observed in the axial skeleton. The highest frequency of lesions (n=24) was observed on the single goat skeleton, a possible female, aged between c.3-7 years at death. This ABG dates to the early phase of the site (470 - 310 BC). The majority of these lesions were recorded as 'other' and are associated with trauma. There were multiple fractures evident on both the lumbar vertebrae and the ribs. Some of these fractures were healed, some were in the process of healing with callus formation and some were not healed. This indicates that at death the animal had suffered recent trauma to the ribs and lower back. There was also evidence of periodontal disease, in addition to an enlarged foramen affecting the fifth lumbar vertebra (Figure 9.111).

a b

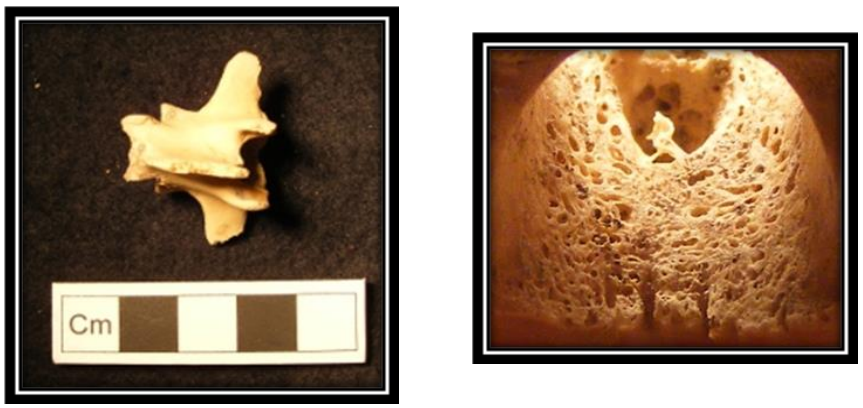
Figure 9.111 Goat lumbar vertebra with enlarged foramen (a), with close-up view of foramen (b) (Photo: Author)

Two sheep/goat ABGs (DA 72 P365 and DA 83 P2273) displayed a porous, lytic lesion affecting the lateral surfaces of the sternum (Figure 9.112).

a b

Figure 9.112 Sheep/goat sternum displaying a porous, lytic lesion on its lateral surface (a), with close-up view of the bone loss (b) (Photo: Author)

Porous, lytic lesions were also observed within the vertebral foramen of a lumbar vertebra (DA 72 P120). This bone also possessed an enlarged foramen within the vertebral foramen (Figure 9.113).



a b

Figure 9.113 Sheep/goat lumbar vertebra (a), with a porous, lytic lesion within the vertebral foramen revealing the trabecular bone structure (Photo: Author)

Summary and Differential Diagnosis

The lesions observed in the four sheep/goat ABGs presented above could potentially be suggestive of infection, although this is difficult to determine as only a small number of skeletal elements were actually affected in each skeleton. The latter would preclude the presence of systemic infection, as would the lack of excessive bone lysis and bone proliferation. However, there are some lesions of specific interest that require discussion. Enlarged foramina observed both within the vertebral foramen and also on the circumferential surfaces of the vertebral body could be suggestive of infection. However, there was no new bone formation associated with these. Therefore, they could just reflect developmental anomalies Porous, lytic lesions within the vertebral foramen and also affecting the lateral surfaces of the sternum fragments are also interesting. The loss of bone in the vertebra may be associated with infection, nutritional deficiency, a metabolic disorder or even osteoporosis in older individuals. One of the ABGs exhibiting this lesion type was greater than 5 years in age (DA 83 P2273). The rest of the bones belonging to this skeleton were noted as being lighter than normal, so osteoporosis should be included on a list of differential diagnoses.

Pig ABGs

Four pig ABGs were recorded (Table 9.36). All but one was listed in the report; the remaining three dated to the early phase and the late (a) phase. Three of the ABGs were juvenile and less than 12 months of age at death. One individual was aged between 1-2 years at death. Sex was unable to be reliably determined.

Table 9.36 Pig ABGs recorded at Danebury Hillfort: Age-at-death and sex determinaton

Phase	Context Number	Age Estimation in months (epiphyseal fusion & tooth eruption)	Tooth Wear (mandible wear score)	Sex Determination	Pathological
Early (470 - 310 BC)	DA 74 P674 LAYER 4	(4-6) - <12	9-10	-	N
	DA 78 P1028 LAYER 4	4-6	-	-	N
Late (a) (270 - 50 BC)	DA 77 P930 LAYER 2	<12	-	-	Y
Not on fiche	DA 73 P499 LAYER 1	(12-18) - <24	19-21	-	N

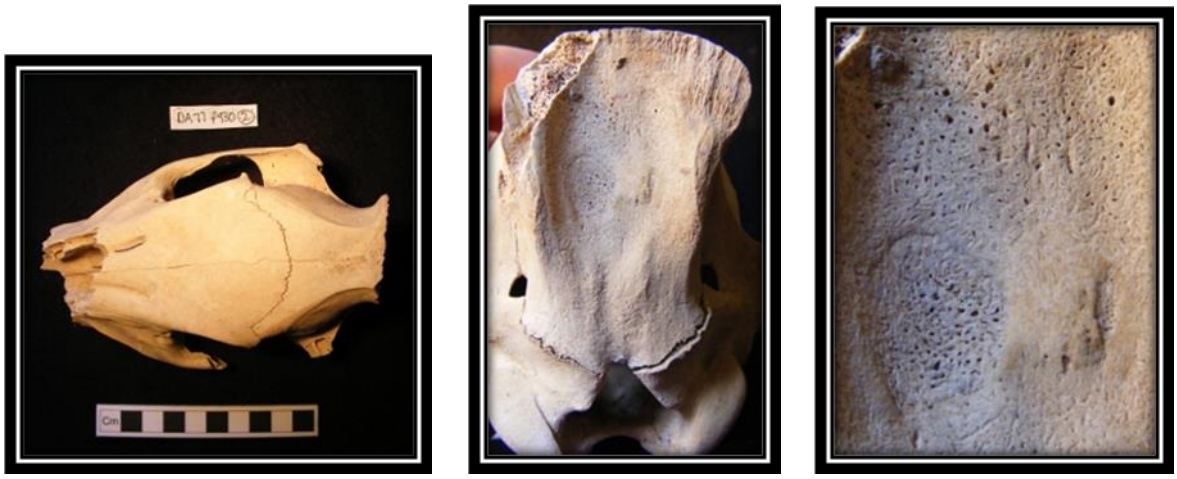
Palaeopathology

Just one of the four ABGs (25%) was pathological (Table 9.37). The skeleton was complete and in a fair-good condition. There was a significant difference in the skeletal distribution of pathological lesions throughout the skeleton at $\alpha = 0.05$ ($X^2 = 11.95$, $p = .0075$, $p < 0.05$, d.f. = 3). This indicates that the distribution is unlikely to be due to chance.

Table 9.37 The frequency of lesion types recorded for the pig ABG

Pig	Frequency of Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
DA 77 P930 LAYER 2	-	2	-	-	-	-

This single pig ABG possessed abnormality on the occipital region of the cranium (Figure 9.114). A shallow indentation was present (almost resembling a thumb print). This was pitted and porous. Porosity was also evident around the indentation and appeared localised to the upper left region of the occipital. This may possibly be associated with localised trauma, a cystic lesion or be related to a nutritional deficiency.



a b c

Figure 9.114 Pig skull (a) displaying shallow indentation and microporosity (b, c) (Photo: Author)

Dog ABGs

Five dog ABGs were recorded (Table 9.38). All but one was listed in the report. They dated to the middle and later phases of the site. Apart from one dog aged less than 6-7 months, the others were all at least 1 year at death. Sex was determined in two individuals through the presence of the baculum. One of these ABGs was recovered from a pit also containing a horse skeleton (DA 72 P321).

Table 9.38 Dog ABGs recorded at Danebury Hillfort: Age-at-death and sex determination

Phase	Context Number	Age Estimation in months (epiphyseal fusion & tooth eruption)	Sex Determination	Pathological
Middle (310 - 270 BC)	DA 71 P51 LAYER 3	>13-16	-	Y
Late (a) (270 - 50 BC)	DA 72 P321 LAYER 5	>12-18	M	Y
	DA 75 P821 LAYER 4	<6-7	-	Y
Late (b) (50 BC – AD 40)	DA 72 P366 LAYER 6	>12-18	-	Y
Not on fiche	DA 83 P2196 LAYER 6	>12-18	M	Y

Palaeopathology

All five dog ABGs were pathological (Table 9.39). One of the five was complete, with the remaining four representing partial skeletons. The remains were in a fair to good condition. The different types of lesion identified and their skeletal distribution are presented in Figures 9.115 & 9.116. There was a significant difference in the skeletal distribution of pathological lesions throughout the skeleton at $\alpha = 0.05$ ($X^2 = 21.0$, $p = .0001$, $p < 0.05$, d.f. = 3). This indicates that the distribution is unlikely to be due to chance.

Table 9.39 The frequency of lesion types recorded for the dog ABGs

Dog	Frequency of Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
DA 71 P51 LAYER 3	-	6	-	-	-	-
DA 72 P321 LAYER 5	-	-	-	-	1	-
DA 75 P821 LAYER 4	1	-	1	-	1	-
DA 72 P366 LAYER 6	-	-	3	-	-	3
DA 83 P2196 LAYER 6	3	2	2	-	2	-

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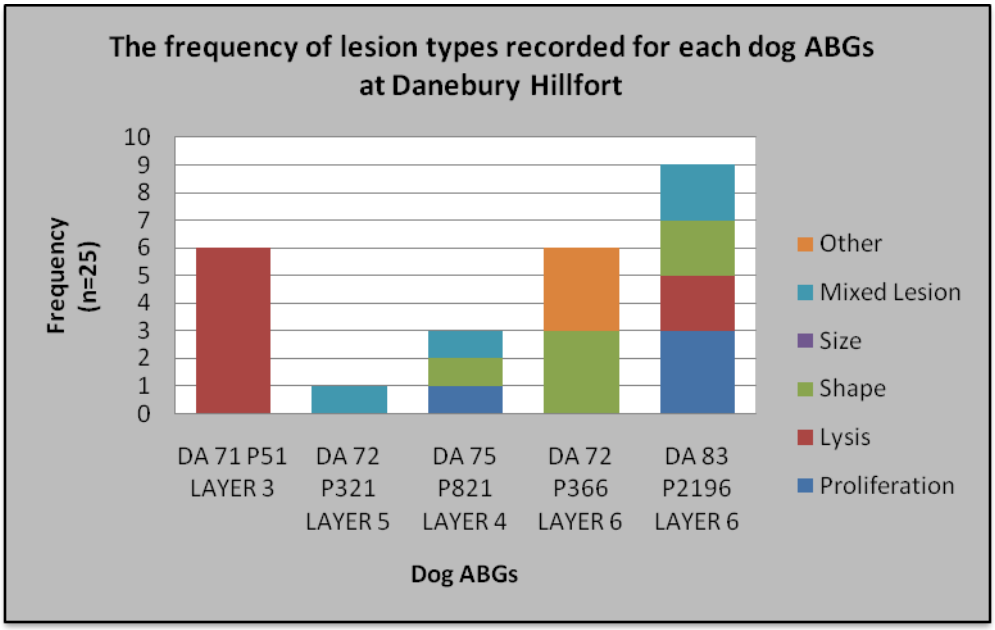

Figure 9.115 Dog ABGs: The frequency of lesion types

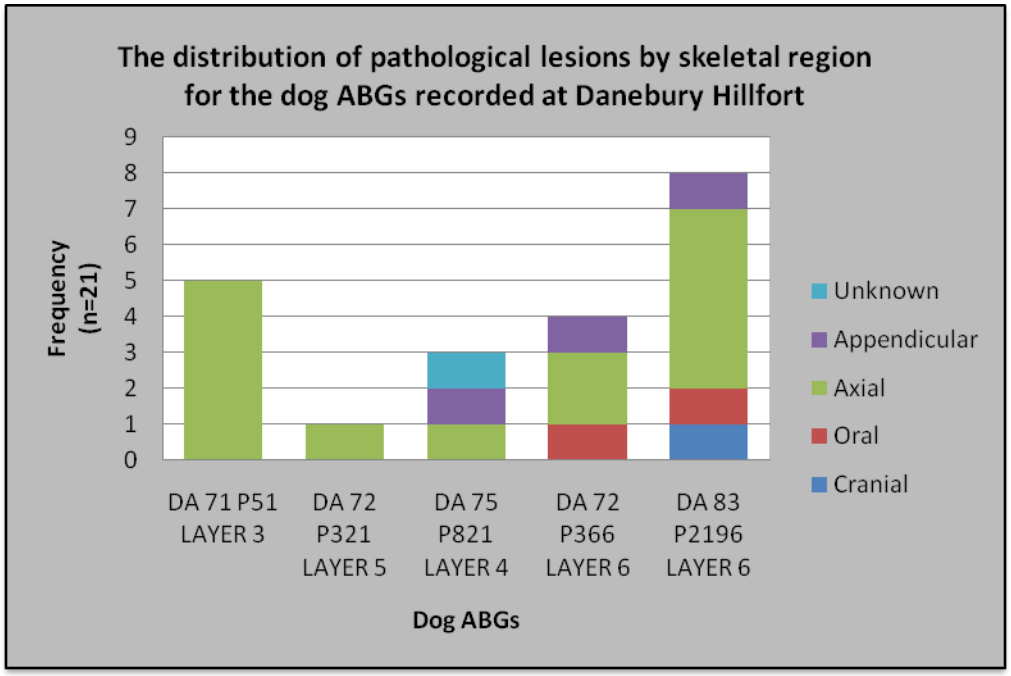

Figure 9.116 Dog ABGs: The distribution of lesions by skeletal region

DA 71 P51

This dog skeleton was aged at least a year at death and dates to the middle phase (310 - 270BC). The skeleton was partially articulated, comprising parts of the axial skeleton and hind limbs. The condition of the bone was fair to good. All of the lesions identified were associated with abnormal bone lysis and were located in the axial skeleton, specifically the lumbar vertebrae and sacrum. The lesions affected the vertebral bodies and in some cases the ventral aspects of the neural arches within the vertebral foramen. There was no new bone formation recorded.

The fifth lumbar vertebra displayed the most striking lesion. Externally, the bone appeared normal. However, when viewed internally, a large space-occupying lesion was observed. The lesion has smooth, remodelled margins with a scalloped appearance in the interior. The limits of the lesion, its smooth interior margins and sclerosis are clearly visible on the radiograph, indicating a chronic condition (Figure 9.117). The lesion did not perforate through the body to the outer surface, and there was no associated new bone formation. Bone loss was also evident on the ventral surface of the neural arch, also visible on the radiograph. Two other lumbar vertebrae and the sacrum were similarly affected indicating the presence of a possible systemic disease process.

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a

b

c

Figure 9.117 Fifth lumbar vertebra (a) with space-occupying lesion within the vertebral foramen (b, c). Bone loss was also evident on the ventral surface of the neural arch, visible on the radiograph (b) (Photo: Author)

Similarly the seventh lumbar vertebra also displays bone lysis, although the destruction is more irregular in this case. The caudal vertebral endplate is partly destroyed with the surviving outer margins displaying pitting and porosity. This destruction can be observed on the radiograph, where once again a sclerotic response can be observed, most prominent at the caudal end of the vertebral body (Figure 9.118).

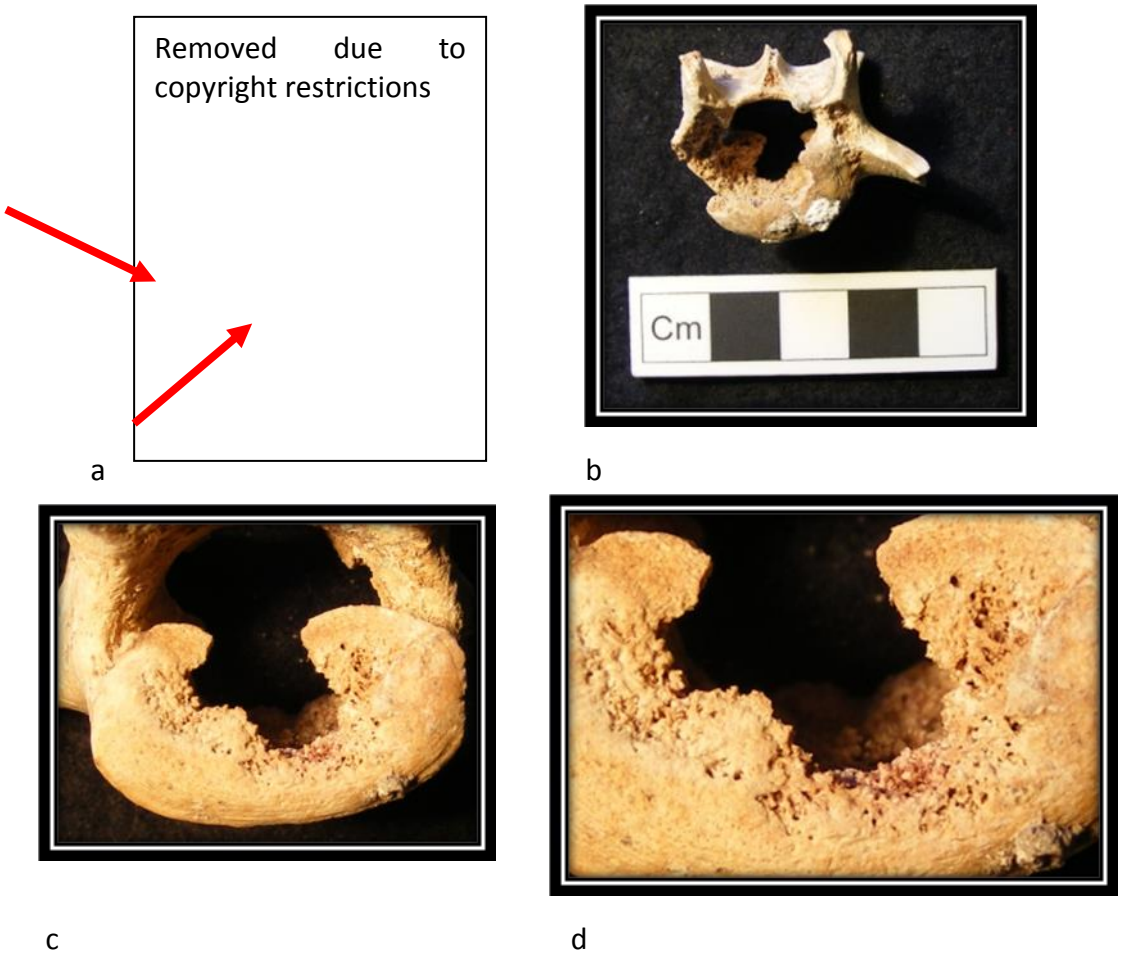


Figure 9.118 Seventh lumbar vertebra displaying destructive lesion of the vertebral body (a, b). Pitting and porosity is also evident in the vertebral end plate (c, d) (Photo: Author)

Summary and Differential Diagnosis

The lesions observed in the lower back region of this dog ABG are purely destructive when viewed macroscopically. There is no new bone proliferation, although the chronic nature of the disease process/condition is indicated by the sclerotic response and remodelled margins evident on the radiographs. There were no similar lesions identified in the rest of the vertebral column suggesting that this

condition was localised to the lumbar region. In terms of differential diagnosis, infection is definitely a candidate, although the lack of new bone formation in the form of periostosis would require careful contemplation. Skeletal infection with MTB complex is highly destructive, and does not always result in a large amount of bone proliferation, unlike in cases of brucellosis where proliferative new bone is a feature (section 4.2.1). Therefore, this disease should be considered. Echinococcus is another disease that warrants consideration, although apart from the ventral aspect of the neural arch, no other posterior vertebral elements are affected, as is often the case with this parasitic disease (section 4.3.1). Secondary metastatic bone tumours, of which the vertebrae in dogs is a predilection site is a possibility. The lesions are described as being primarily osteolytic and can lead to structural collapse (section 4.5.2).

The remaining dog ABGs predominantly display lesions associated with trauma affecting the axial and appendicular regions of the skeleton. The youngest dog represented possessed an isolated plaque of new bone formation on the visceral surface of a rib, close to the neck region. This would suggest either trauma or infection, with the position of the lesion strongly suggestive of respiratory infection.

Horse ABGs

Two horse ABGs were recorded (Table 9.40). One dated to the middle phase and one to the earlier part of the late phase at this site. The oldest horse was at least 8 years of age based upon the wear of the incisor teeth. This individual was cautiously recorded as male based upon the presence and size of the canines. The remaining

horse was younger, aged between of 2 - 3 ½ years at death. This horse was recovered from a pit along with a dog skeleton.

Table 9.40 Horse ABGs recorded at Danebury Hillfort: Age-at-death and sex determination

Phase	Context Number	Age Estimation in months (epiphyseal fusion & tooth eruption)	Crown height (yrs)	Sex Determination	Pathological
Middle (310 - 270 BC)	DA74 P562	>36-42	>8*	M?	Y
Late (a) (270 - 50 BC)	DA 72 P321 LAYER 5	(20-24) – <(36-42)	-	-	Y

*based upon incisor wear and appearance of the infundibulum as cheek teeth were unable to be measured

Palaeopathology

Both horse ABGs were pathological (Table 9.41). The skeletons were almost complete and in a fair to good condition. The different types of lesion identified and their skeletal distribution are presented in Figures 9.119 & 9.120. There was a significant difference in the skeletal distribution of pathological lesions throughout the affected regions of the skeleton at $\alpha = 0.05$ ($X^2 = 4.76$, $p = .0290$, $p < 0.05$, d.f. = 1). This indicates that the distribution is unlikely to be due to chance.

Table 9.41 The frequency of lesion types recorded for the horse ABGs

Horse	Frequency of Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
DA74 P562	10	2	-	8	-	22
DA 72 P321 LAYER 5	1	1	-	-	-	-

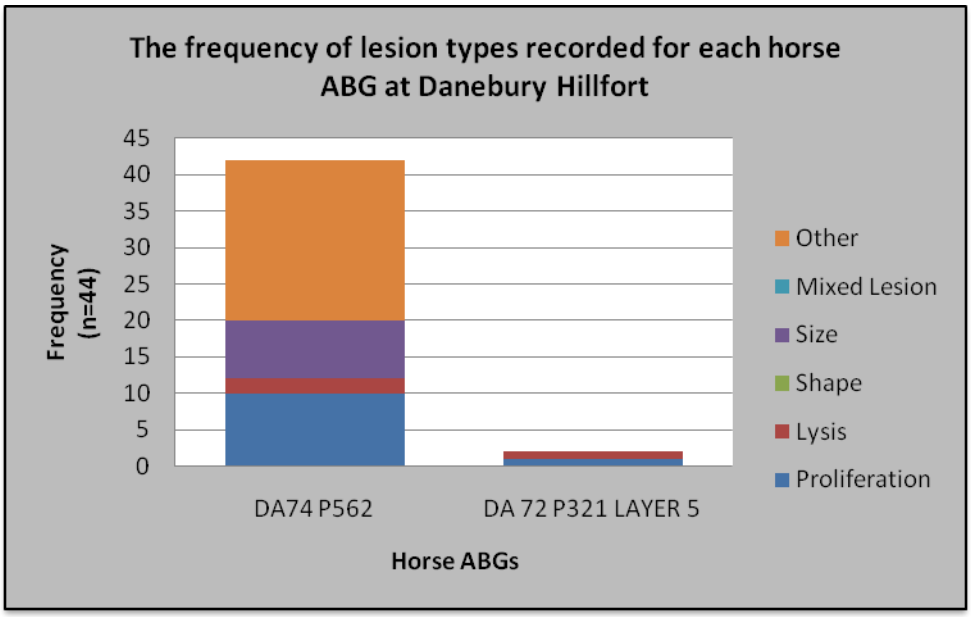


Figure 9.119 Horse ABGs: The frequency of lesion types

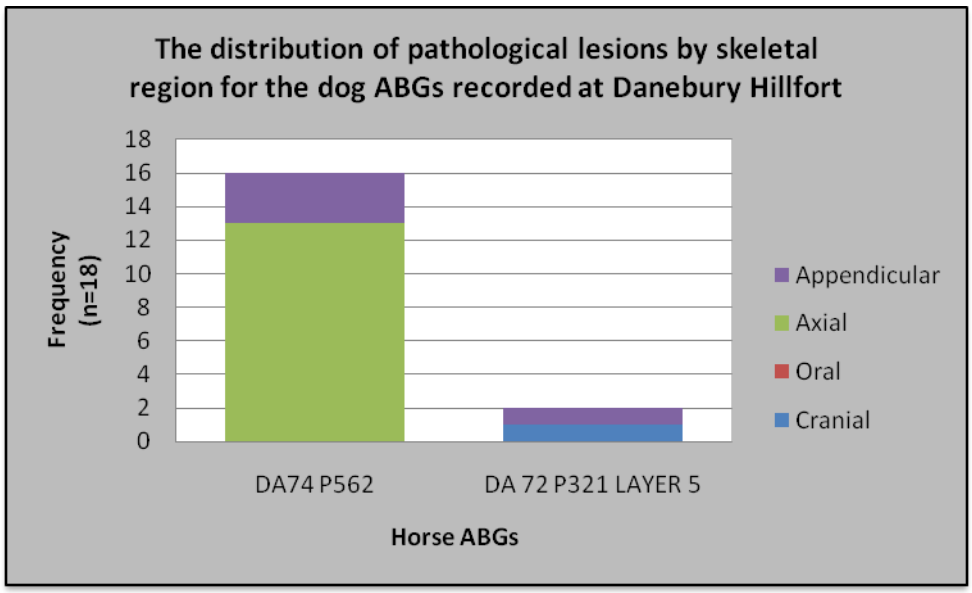


Figure 9.120 Dog ABGs: The distribution of lesions by skeletal region

DA 74 P562

This possible male horse was the oldest of the two recorded and dates to the middle phase (310 – 270BC). It possessed the highest frequency of pathological lesions, representing 95% of the total number of lesions recorded. The majority of these were located in the axial skeleton, specifically the vertebral column. Over half of the lesions observed were recorded as 'other'. These all relate to trauma and all represent visible microfractures in ossified costal cartilage fragments. If this lesion type is disregarded, the lesions observed are predominantly associated with abnormal bone formation, abnormal bone size and abnormal bone lysis. Eight vertebrae (T6-T7, T10-T15 and L1) possessed enlarged vertebral foramina (Figure 9.121). These were not present in all the vertebrae but, in those where they were enlarged, they were of a similar size.

Figure 9.121 Horse lumbar vertebrae displaying enlarged foramen visible on the lateral vertebral bodies (Photo: Author)

The fourth and fifth lumbar vertebrae displayed ankylosis of the transverse processes; the vertebral bodies were unaffected. The last lumbar vertebra had also become ankylosed to the sacrum, but the disc space had been partially retained. Two tarsals were also ankylosed and roughened on the surface that articulates with the proximal metatarsal. Compact bone proliferation on the proximal cranial diaphysis of the metatarsal and mirrored on the already ankylosed tarsals indicates that these skeletal elements were in the process of becoming ankylosed (Figure 9.122).

Figure 9.122 Ankylosed tarsals in the process of becoming ankylosed to the proximal metatarsal

Small spicules of compact bone were observed on the dorsal surface of the atlas. These potentially reflect the beginnings of an enthesophyte, probably associated with the nuchal ligament. A small syndesmophyte was also observed projecting cranially on the ventral surface of a thoracic vertebral body (T15). This is probably associated with the anterior longitudinal ligament.

Summary and Differential Diagnosis

Apart from the multiple enlarged foramina in the vertebral bodies, there were no other potential indicators of infection in this horse ABG. The enlarged foramina were not present on all the vertebrae, which may preclude them being a 'normal' occurrence. However, they were quite uniform in size where they did appear and were not associated with any new bone formation. There is the possibility that they may reflect a non-metric trait in this instance or just be a developmental anomaly. The rest of the lesions point towards arthropathy and/or trauma, perhaps associated with either riding or traction.

Horse DA 72 P321, the younger of the two, possessed only two palaeopathological lesions. A fissure present in the centre of the glenoid fossa (possibly a non-pathological feature) (see Baker and Brothwell 1980) and an enthesophyte on the occipital bone. The latter suggests trauma to the attachment region of the nuchal ligament, a lesion that may also indicate infection (see section 4.2.1) as discussed in relation to the disarticulated example sampled for aDNA testing (section 9.12).

Summary

The faunal assemblage associated with Danebury Hillfort totalled 138,528 fragments. The size of this precluded a thorough palaeopathological analysis for the purposes of this research. However, a sample of known palaeopathological bones extracted from the assemblage and previously analysed by Prof. Brothwell was re-analysed. The level at which this sample is representative of the assemblage as a whole is questionable, therefore, no statistical analyses were carried out. Three hundred and twenty-four types of pathology were recorded on a sample of 183 bones, equating to less than 1% of the entire assemblage. Of the species identified, sheep/goat possessed the most pathological lesions, comprising 37% of the sample recorded, followed by cattle (26%) and pig (15%). The palaeopathology exhibited was, in some cases, extreme but healed. This provides insight into animal management and the care of sick/injured livestock at Danebury Hillfort. Two bones were sampled for aDNA, a LTM lumbar vertebra and a horse cranium and contiguous atlas vertebra (section 9.12). In addition, twenty-seven 'special animal deposits' recovered at Danebury Hillfort (ABGs) were recorded. The identification of palaeopathology in a number of these possibly supports the notion that some may have been buried as a result of disease. Significant differences were identified in all species of ABG at $\alpha = 0.05$, illustrating that the distribution of the lesions was not due to chance.

9.8 Westness, Rousay, Orkney

The faunal assemblage recovered from the excavations at Westness was selected because of the suspected presence of MTB Complex in the indigenous Pictish human population. Two individuals buried in the cemetery that was later used by the Viking settlers associated with the nearby farmstead settlement and boat noust possessed macroscopic lesions suggestive of MTB complex disease. Although these skeletons appear to belong to the native Pictish population, they potentially represent the only evidence to date for this disease in the Scottish Northern Isles. They also represent the presence of a possible reservoir of infection for the migrating Vikings.

9.8.1 The Disarticulated Assemblage

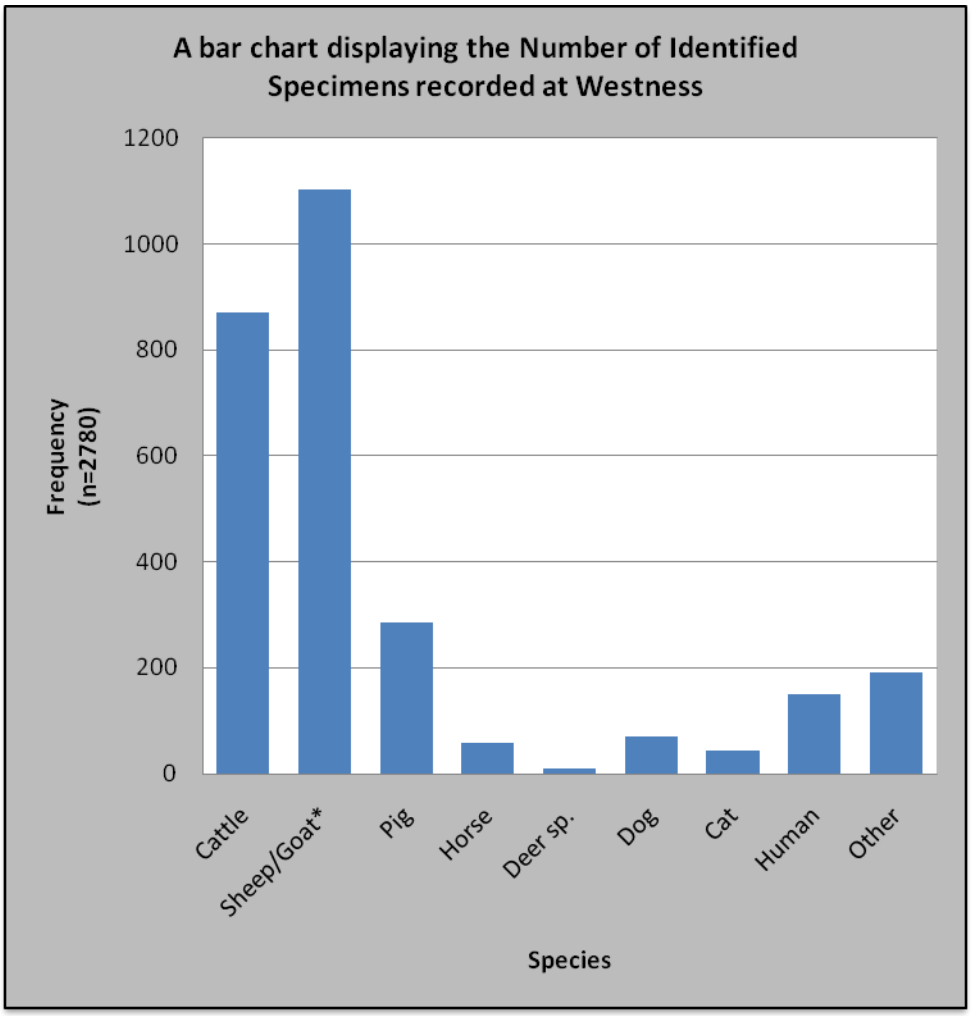
The disarticulated assemblage was assessed by researchers at the Museum of Zoology, University of Bergen, and totalled 20,807 fragments. The full excavation report is yet to be published. For the purposes of this research, the mammal bones were re-assessed and any pathological lesions identified recorded. Unfortunately, the assemblage was unable to be accurately dated as there was an absence of contextual and phasing data available. However, the Director of the excavations (Dr. Sigrid Kaland) stated that the faunal assemblage recovered was associated with the primary use of the three longhouse structures (Kaland pers. comm.). Therefore, it would appear reasonable to assume that this faunal assemblage was late Norse at the very latest and, therefore, represents an interesting dataset, especially in the context of contact between the indigenous population and incoming Viking settlers.

As was the case with the assessment of Wetwang Slack, time constraints precluded the full recording of the disarticulated assemblage. Therefore, a basic assessment was conducted in order to establish a Total Number of Fragment (TNF) count and basic overview of species ratios (Number of Identifiable Specimens, NISP) (Table 9.42, Figure 9.123). Unfortunately, this meant that more detailed information pertaining to age-at-death, skeletal element representation and sex determination was not available for further interpretation.

Table 9.42 Number of Identified Specimens at Westness

SPECIES	NISP	%NISP
Cattle	870	31
Sheep/Goat*	1102	40
Pig	286	10
Horse	57	2
Deer sp.	10	-
Dog	71	3
Cat	43	2
Human	150	5
Other	191	7
TOTAL No. IDENTIFIED	**2780**	**-**
LTM	843	-
MTM	3813	-
STM	64	-
Unidentified	1	-
TOTAL No. UNIDENTIFIED	**4721**	**-**
TNF	**7501**	**-**

***contains 1 x sheep and 1 x goat**
Key: Large Terrestrial Mammals (LTM); Medium Terrestrial Mammals (MTM); Small Terrestrial Mammals (STM)



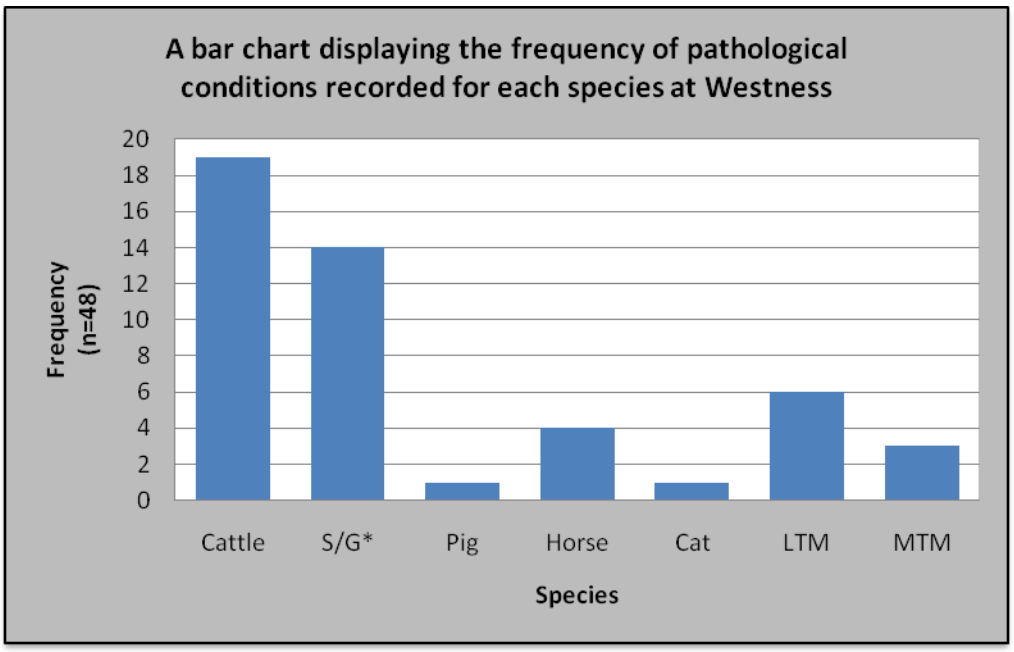
***contains 1 x sheep and 1 x goat**

Figure 9.123 Number of Identified Specimens recorded at Westness

Palaeopathology

Seventy-one types of pathology were recorded on 48 bones, equating to less than 1% of the entire assemblage. Seven of these bones were labelled as unstratified. They have been included in this analysis because of their interesting pathological lesions and because the assemblage is unable to be accurately phased. Sheep/goat was the most frequently identified species, but it was cattle that were most frequently pathological (40% vs 29% for sheep/goat) (Figure 9.124). However, this

difference was not statistically significant at α = 0.05 (X^2 = 2.47, p =.1164, p > 0.05, d.f. = 1).



***includes 1 x goat**

Figure 9.124 The frequency of pathological conditions recorded by species at Westness

A summary of palaeopathological lesion types

Table 9.43 and Figure 9.125 illustrate the frequency of pathological conditions by species for the assemblage at Westness. Abnormal bone lysis (31%) and abnormal bone proliferation (31%) represent the most frequent lesion types recorded followed by 'other' (23%). Porous, lytic lesions (36%) dominate the bone lysis lesion types, followed by lesions associated with osteochondrosis manifesta (23%), cortical clefts (possibly non-pathological) (14%), pitting/porosity (14%), alveolar resorption (9%) and a single cystic lesion (5%). Osteophyte formation comprised half of the abnormal bone formation lesion types (50%), followed by periostosis (27%),

enthesophyte formation (9%), nodule (9%) and other (5%). The 'other' category comprised the following lesion types: congenital (19%), hypercementosis of tooth roots (25%), pulp cavity exposure (PCE) (19%), ante-mortem tooth loss (13%), calculus (6%), eburnation (13%) and abnormal attrition (6%).

Table 9.43 Westness: Summary of pathological lesion types by species

Species Affected	Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed Lesion	Other
Cattle	14	9	1	-	1	4
Sheep/Goat*	4	6	-	1	2	9
Horse	1	-	1	2	1	1
Pig	-	-	-	-	-	2
Cat	1	-	-	-	-	-
LTM	-	6	-	1	-	-
MTM	2	1	-	1	-	-
TOTAL No.	**22**	**22**	**2**	**5**	**4**	**16**
TOTAL %	**31**	**31**	**3**	**7**	**6**	**23**

***includes 1 x goat**

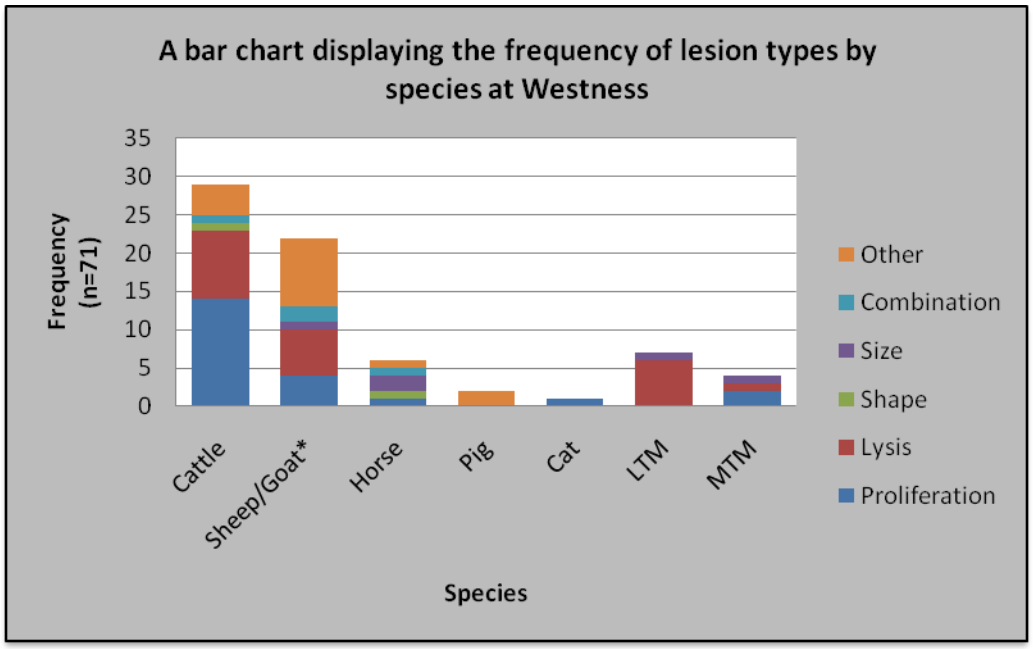


Figure 9.125 The frequency of lesion types by species at Westness

The remaining pathology types include five cases of abnormal bone size. These consisted of four enlarged foramina, affecting two horse caudal vertebrae, an LTM sacrum and a MTM thoracic vertebra. The remaining case refers to widening of the alveolar bone in a goat mandible. There were also four mixed lesions: a sheep/goat contiguous second and third phalanx displaying gross palaeopathological change to the articular surfaces, possibly representing a traumatic arthropathy, a cattle thoracic vertebra with multiple lesions and a horse tarsal with a space-occupying lesion and pitting/porosity both suggestive of infectious arthropathies. Two cases of abnormal bone shape were also recorded. These referred to asymmetry of a cattle distal metacarpal condyle and asymmetry of a horse caudal vertebra.

A summary of palaeopathological lesion characteristics: aetiologies

Table 9.44 and Figure 9.126 illustrate the frequency of pathological conditions recorded by species at Westness. Non-specific bone lysis (25%) was the most frequent category, followed by arthropathy (18%), other (18%) oral pathology (14%), mixed lesion (8%), non-specific bone proliferation (8%), congenital (6%), and trauma (4%).

Table 9.44 Westness: Summary of aetiologies by species

Species Affected	General Aetiology Categories							
	Oral	Trauma	Arthropathy	Congenital	Infection?		Mixed lesion	Other
					Non-specific bone proliferation	Non-specific bone lysis		
Cattle	1	1	8	1	-	4	1	3
Sheep/Goat *	5	-	-	1	2	-	2	5
Horse	-	1	-	1	-	2	1	-
Pig	1	-	-	-	-	-	-	-
Cat	-	-	-	-	-	-	-	1
LTM	-	-	1	-	-	6	-	-
MTM	-	-	-	-	2	1	-	-
TOTAL No.	**7**	**2**	**9**	**3**	**4**	**13**	**4**	**9**
TOTAL %	**14**	**4**	**18**	**6**	**8**	**25**	**8**	**18**

***includes 1 x goat**

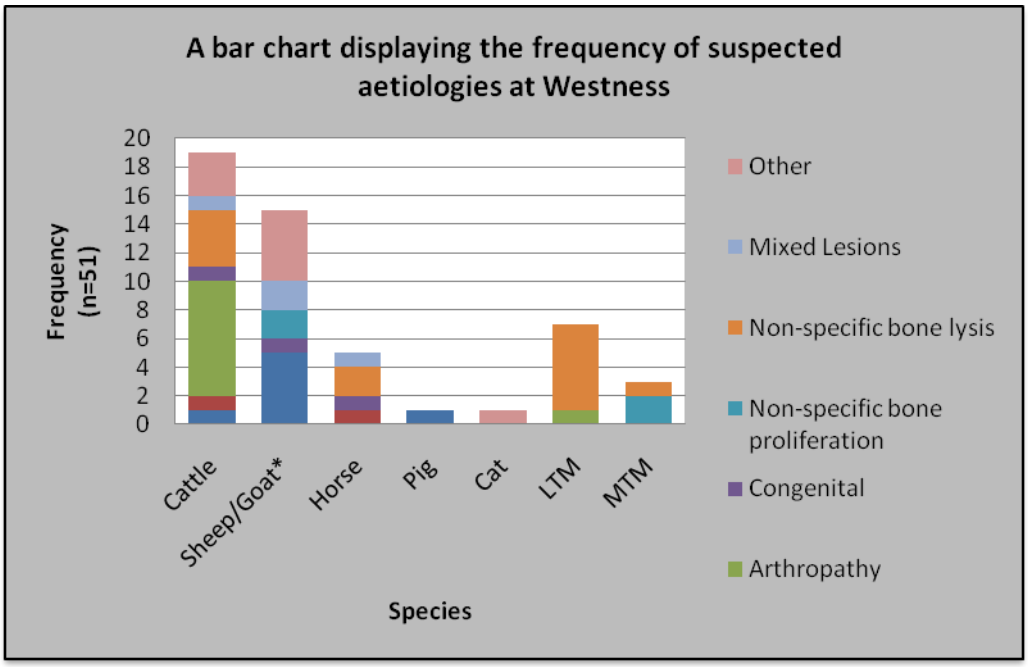


Figure 9.126 The frequency of aetiologies recorded by species at Westness

There was not enough data to conduct a thorough statistical analysis. However, two chi-square tests were conducted to determine if the differences exhibited in the oral pathology and other (OCM) aetiology categories between sheep/goat and cattle were significant or not. Both tests were not significant at $\alpha = 0.05$ (Table 9.45).

Table 9.45 X^2 results: cattle and sheep/goat aetiologies

Aetiology (cattle vs. sheep/goat)	$X^2_{(1)}$	*P* value	H_0 Accept or reject?
Oral pathology	1.84	.1750	Accept
Other (Osteochondrosis manifesta)	1.18	.2768	Accept

Evidence for possible infection and differential diagnosis

A number of the pathological lesions recorded may potentially indicate the presence of infection. These include those categorised as non-specific bone lysis and non-specific bone proliferation, in addition to one trauma case and two mixed lesion cases. Non-specific bone lysis totalled 25% of the lesion types. These comprised porous, lytic lesions (53%), enlarged foramina (27%) pitting/porosity (13%) and a single cystic lesion (7%) (Figure 9.127). All of the lesions were identified in the axial region of the skeleton. Unfortunately, there was not enough variability in the data to compare this lesion distribution statistically.

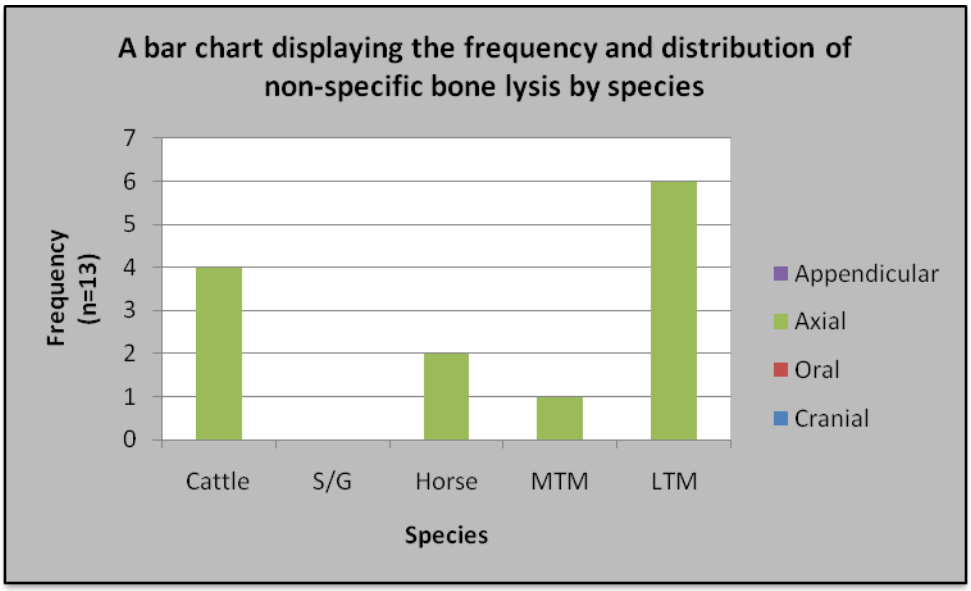


Figure 9.127 Non-specific bone lysis by skeletal region at Westness

Porous, lytic lesions were the most frequent type of non-specific bone lysis recorded, representing half of the lesions observed (53%). Eight cases were identified affecting the vertebral bodies of cattle (Figure 9.128), LTM and MTM. This bone loss may be related to infection, nutritional deficiency, metabolic disorder or

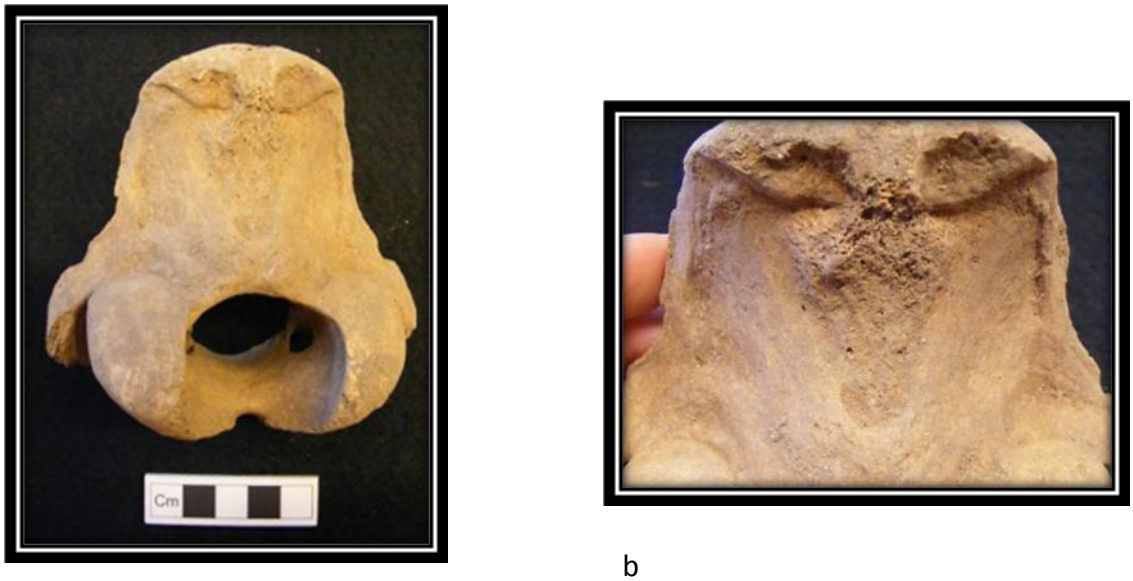
osteoporosis. The latter is unlikely as the rest of the bone was unaffected and not unusually light or fragile.

a b

Figure 9.128 Cattle cervical vertebrae (a), displaying porous, lytic lesions within the vertebral foramen revealing the underlying trabecular bone (b) (Photo: Author)

Enlarged foramina comprised 27% of the lesions recorded, affecting two horse caudal vertebrae, MTM vertebra and a LTM sacrum fragment. These could represent normal variation or constitute a developmental anomaly. Alternatively, they may represent the presence of infection associated with the blood vessels. Two cases of pitting/porosity (13%) were identified, along with a single space-occupying lesion (7%). In one case, these lesion types were identified on the same bone. A LTM thoracic spinous process possessed pitting on one articular facet with a small, space-occupying lesion just proximal to this at the base of the spine, possibly related to the interspinous ligament. The other case of pitting was identified within the vertebral foramen of LTM thoracic vertebra.

All four examples of non-specific bone proliferation identified were isolated cases of periostosis affecting the oral and axial regions of the skeleton. These were located on a sheep/goat mandible and two MTM ribs. Two patches of new bone formation were observed on the lingual and buccal sides of a sheep/goat mandible. One was woven in appearance suggesting an active process at death and one was compact. These instances of periostosis may have been related to recurring periodontal disease or could be related to trauma or both. The periostosis on the MTM ribs was located on the visceral surface, indicating the presence of a respiratory infection. An enthesophyte located on the occipital region of a horse skull is categorised as trauma, but this type of lesion may also be associated with infection involving the nuchal ligament (section 4.2.1). The enthesophyte is not especially exuberant and there is no additional bone loss that may suggest infection. Therefore, it may represent an example of poll evil or it may be just be trauma or be age-related.



a

b

Figure 9.129 Occipital region of a horse cranium (a) with enthesophyte possibly associated with infection (b) (Photo: Author)

Four bones were identified with multiple lesions and were categorised as mixed. Two of these possess lesions that appear infective in origin. The first is a horse tarsal with a space-occupying lesion located on the proximal articular surface (Figure 9.130). This lesion is shallow and exposes the trabecular bone. Although irregular in shape, the lesion does display defined margins. There is associated pitting around the periphery of the lesion. This lesion suggests the presence of a destructive infectious process within the joint of this lower hindlimb. The lesion is shallow, which may suggest it was contained to a certain degree or that death occurred before further advancement of the process. MTB complex would definitely be on a list of differential diagnoses for this type of lesion, although a non-specific septic arthritis would also require consideration. The lack of new bone proliferation may point towards a purely osteolytic process like a secondary metastatic bone tumour or a benign cyst.

a b

Figure 9.130 Horse tarsal (a) displaying space-occupying lesion exposing the trabecular bone (b) (Photo: Author)

The second case involves a cattle thoracic vertebra (Figure 9.131). Only the central portion of the cranial epiphysis survives, but on the lower extent of this microporosity, roughening and eburnation can be seen, indicating a degenerative change. The exposed trabecular bone beneath the detached/destroyed epiphysis possesses a number of small cystic lesions, varying in size. This vertebra resembles the example identified at Danebury Hillfort, although the lesions in the example from Danebury are more destructive. The aDNA results for the Danebury example would potentially shed some light on these lesion types (see section 9.12).

a b

Figure 9.131 Cattle thoracic vertebra (a) displaying microporosity, roughening and eburnation, with subchondral cystic lesions (b) (Photo: Author)

Summary

The faunal assemblage from Westness totalled 20,807 fragments. The domestic mammal bone was re-assessed for the purposes of this research (n=7501). Sheep/goat dominated the species identified, followed by cattle and pig. Seventy-one types of pathology were recorded on 48 bones, equating to less than 1% of the entire assemblage. Although, sheep/goat possessed the highest NISP count, cattle bones were more frequently identified as pathological. However, this difference was not statistically significant at $\alpha = 0.05$. None of these bones were sampled for aDNA analysis. However, the presence of MTB complex in the indigenous human population suggests a possible reservoir of infection for the incoming Viking settlers and their livestock.

9.9 Hofstaðir, Mývatnssveit, Iceland

The faunal assemblage recovered from the excavations at Hofstaðir was selected for two reasons: the size of the Viking Age faunal assemblage (TNF 102,759) and the presence of a contemporary human population with suspected TB (section 5.8.2). Hofstaðir is described as a high status Viking Age farmstead, therefore, the comparison between the palaeopathology identified at this site and the lower status farmsteads of Hrísheimar (section 9.10) and Sveigakot (section 9.11) is potentially interesting.

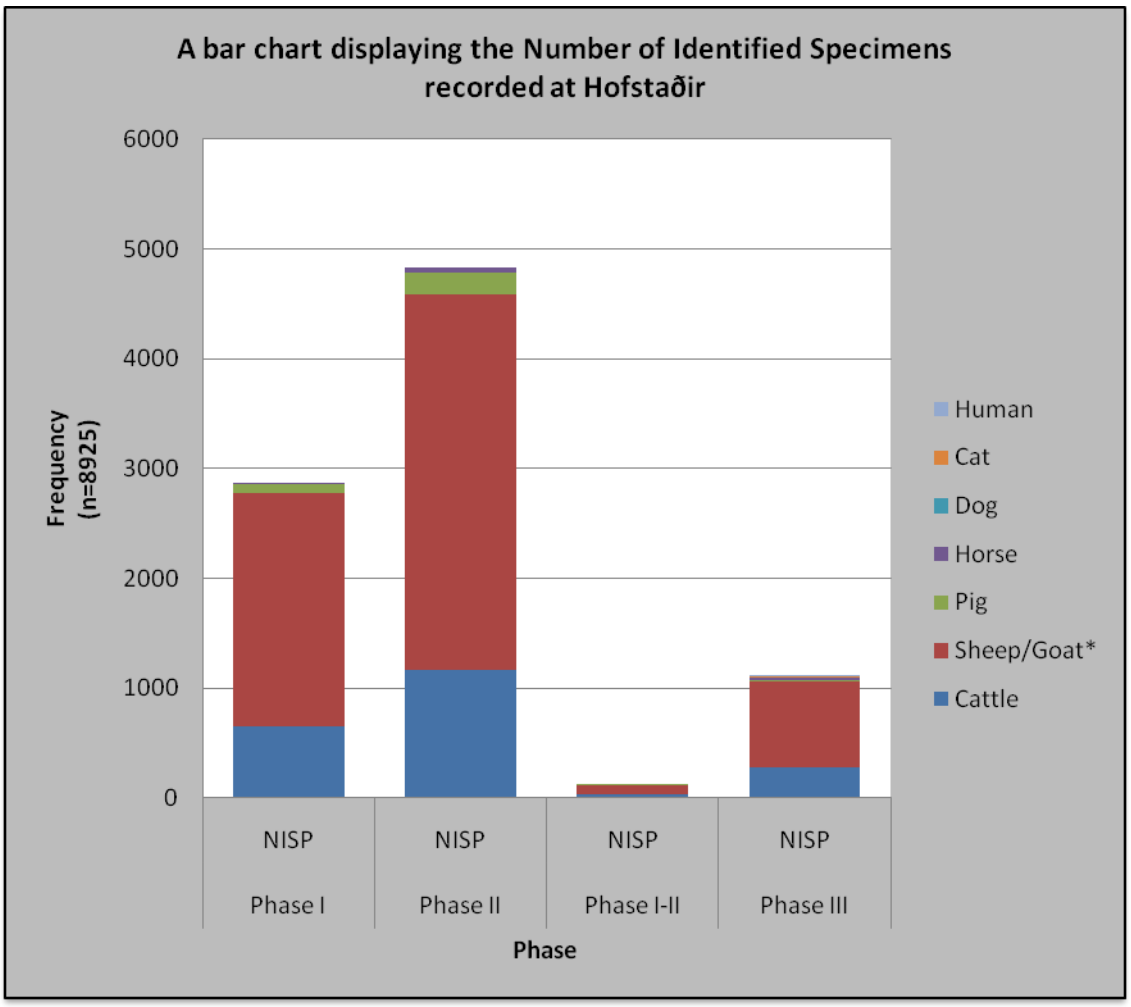
9.9.1 The Disarticulated Assemblage

The disarticulated assemblage was analysed, recorded and reported on by researchers at Hunter College Zooarchaeology Laboratory, City University of New York (CUNY). The assemblage in its entirety totalled 109,373 fragments, with the greater majority (n=102,759) associated with the three main Viking Age phases (McGovern *et al.* 2009). The majority of the assemblage, particularly the quantifiable material is curated by the Hunter Laboratory; un-quantifiable fragments were returned to Iceland prior to the present researcher's visit. As a result of this, only the quantifiable material associated with the domestic mammal species and dating to one of the three Viking Age phases spanning the 10-11th centuries was recorded (Table 9.46).

Table 9.46 Number of Identified Specimens at Hofstaðir: Domestic species (Data from McGovern *et al.* 2009: table 4.3)

Domestic Species	Phase I		Phase II		Phase I-II		Phase III	
	NISP	*%NISP*	NISP	*%NISP*	NISP	*%NISP*	NISP	*%NISP*
Cattle	646	*22*	1163	*24*	29	*25*	276	*25*
Sheep/Goat	1820	*63*	3083	*64*	83	*72*	716	*65*
Sheep	274	*10*	282	*6*	2	*2*	62	*6*
Goat	36	*1*	58	*1*	-	-	6	*1*
Pig	86	*3*	199	*4*	1	*1*	13	*1*
Horse	12	-	42	*1*	-	-	19	*2*
Dog	-	-	-	-	-	-	2	-
Cat	-	-	-	-	-	-	13	*1*
Human	-	-	-	-	-	-	2	-
TOTAL No. IDENTIFIED	**2874**	**-**	**4827**	**-**	**115**	**-**	**1109**	**-**
LTM	727	-	1366	-	30	-	259	-
MTM	3172	-	4934	-	128	-	816	-
STM	19	-	91	-		-	2	-
Unidentified	17694	-	31285	-	1008	-	4179	-
TOTAL No. UNIDENTIFIED	**34983**	**-**	**59669**	**-**	**1310**	**-**	**6797**	**-**
TNF (Domestic species + unidentified)	**37857**	**-**	**64496**	**-**	**1425**	**-**	**7906**	**-**

Key: Large Terrestrial Mammals (LTM); Medium Terrestrial Mammals (MTM); Small Terrestrial Mammals (STM)



***sheep/goat includes separate sheep and goat identifications (see table X)**

Figure 9.132 Number of Identified Specimens recorded at Hofstaðir

Palaeopathology

Two hundred and twenty one types of pathology were recorded on 188 bones, equating to less than 1% of the entire assemblage. Sheep/goat was the most frequently affected species (71%), followed by cattle (25%) (Figure 9.133). The low frequency of pathological LTM and MTM fragments is a reflection of absence of the non-quantifiable fragments. There was no statistical difference between the

frequency of palaeopathology in sheep/goat and cattle at α = 0.05 (X^2 = .14, p = 7051, p > 0.05, d.f. = 1).

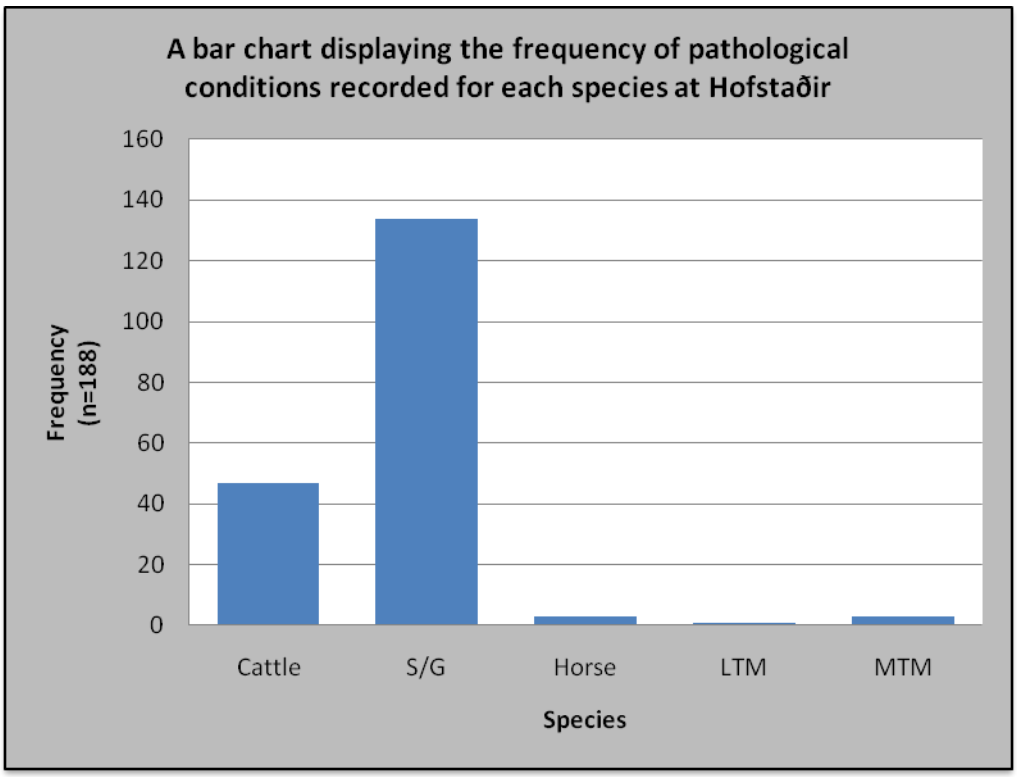


Figure 9.133 The frequency of pathological conditions recorded by species at Hofstaðir

A summary of palaeopathological lesion types

Table 9.47 and Figure 9.134 illustrate the frequency of pathological conditions by species for the assemblage at Hofstaðir. Abnormal bone proliferation (36%) and other (30%) represent the most frequent lesion types recorded, followed by abnormal bone lysis (25%), size (4%), shape (2%) and mixed lesion (2%). Osteophyte formation comprised over half of the abnormal bone formation lesion types (54%), followed by periostosis (34%), enthesophyte formation (8%) and compact bone nodule (3%). The 'other' category comprised the following lesion types: abnormal attrition (42%), ante-mortem tooth loss (13%), malocclusion (9%), tooth

misalignment (9%), pulp cavity exposure (PCE) (6%), ventral margin disturbance (6%), horn-core indentations (4%), congenitally absent tooth (4%), congenital tooth malformation (3%), eburnation (1%), and hypercementosis of tooth roots (1%). The lesion types comprising abnormal bone lysis were as follows: osteochondrosis manifesta (OCM) (35%), alveolar resorption (31%), porous, lytic lesions (11%), cortical clefts (possibly non-pathological) (9%), pitting/porosity (7%), cystic lesions (4%) and a single irregular lytic lesion (2%).

Table 9.47 Hofstaðir: Summary of pathological lesion types by species

Species Affected	**Lesion Type**					
	Proliferation	**Lysis**	**Shape**	**Size**	**Mixed Lesion**	**Other**
Cattle	50	9	1	1	-	1
Sheep/Goat	23	47	4	8	2	66
Horse	5	-	-	-	-	-
LTM	1	-	-	-	-	-
MTM	-	-	-	-	3	-
TOTAL No.	**79**	**56**	**5**	**9**	**5**	**67**
TOTAL %	**36**	**25**	**2**	**4**	**2**	**30**

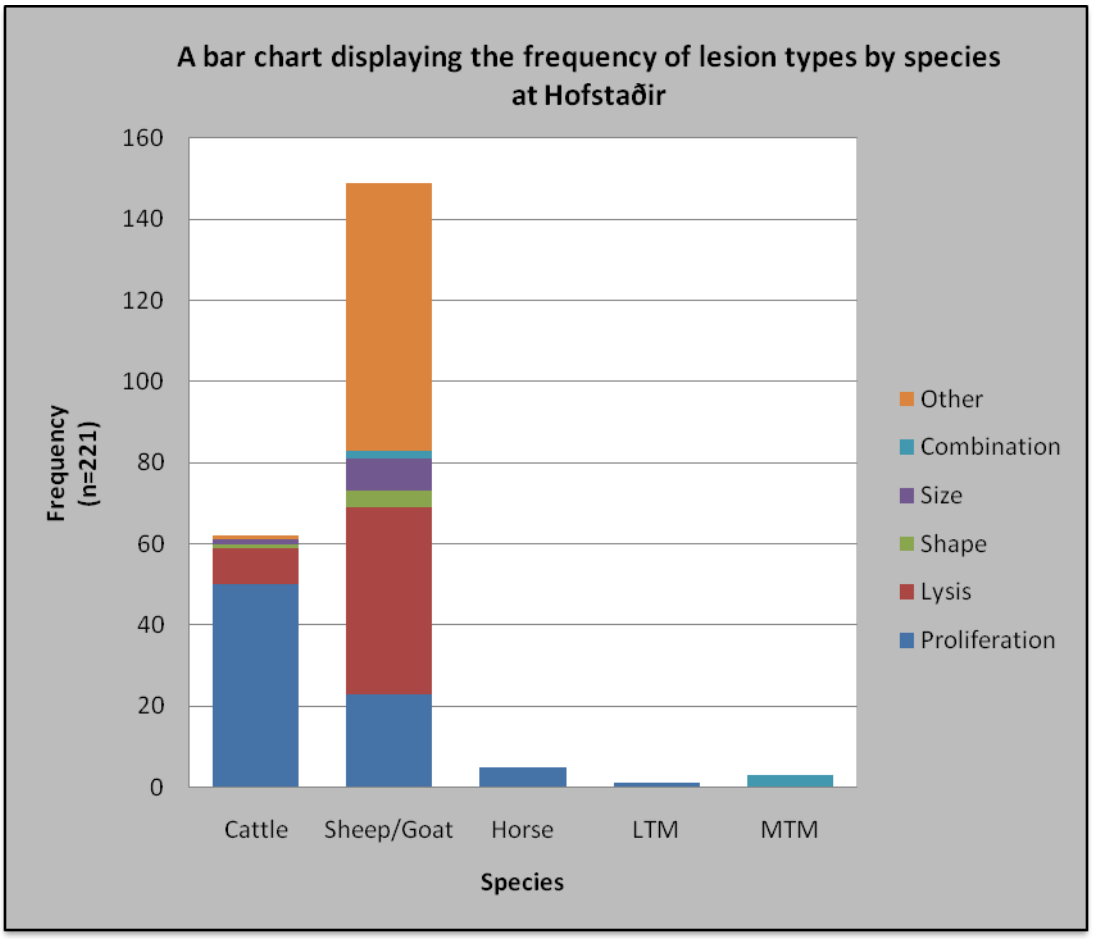


Figure 9.134 The frequency of lesion types by species at Hofstaðir

The remaining pathology types include five cases of abnormal bone shape, five mixed lesion cases and nine cases of abnormal bone size. Abnormal bone shape consisted of a cattle metatarsal with asymmetry of the distal condyles and four dysplastic sheep/goat long bones with no obvious macroscopic evidence for fracture. The mixed lesion cases consisted of a sheep/goat radius and ulna with possible osteomyelitis following trauma, three MTM fragments (2 x rib and 1 unidentified) with fractures and callus formation and a sheep/goat first phalanx with exuberant bone formation and bone lysis possibly representing a traumatic

arthropathy. The cases of abnormal bone size included a cattle caudal vertebra with an enlarged foramen and several examples of widening of the alveolus in sheep/goat mandibles.

A summary of palaeopathological lesion characteristics: aetiologies

Table 9.48 and Figure 9.135 illustrate the frequency of pathological conditions recorded by species at Hofstaðir. Oral pathology was the most frequent category (45%), followed by arthropathy (18%), non-specific bone proliferation (12%), other (11%), trauma (7%), non-specific bone lysis (5%) and congenital (3%).

Table 9.48 Hofstaðir: Summary of aetiologies by species

Species Affected	General Aetiology Categories							
	Oral	Trauma	Arthropathy	Congenital	Infection?		Mixed lesion	Other
					Non-specific bone proliferation	Non-specific bone lysis		
Cattle	-	3	36	4	6	3	-	3
Sheep/Goat	96	8	1	2	17	8	-	20
Horse	-	1	1	-	2	-	-	-
LTM	-	-	-	-	1	-	-	-
MTM	-	3	-	-	-	-	-	-
TOTAL No.	**96**	**15**	**38**	**6**	**26**	**11**	**-**	**23**
TOTAL %	**45**	**7**	**18**	**3**	**12**	**5**	**-**	**11**

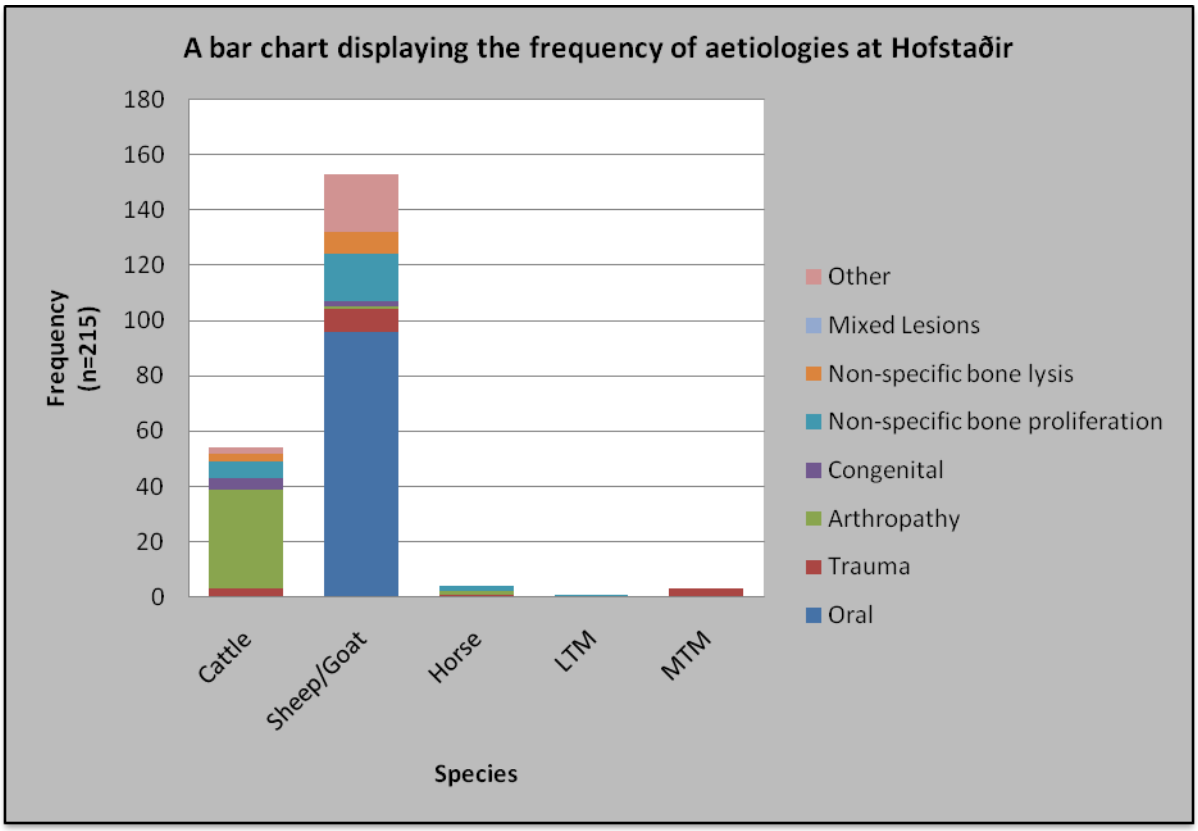


Figure 9.135 The frequency of aetiologies recorded by species at Hofstaðir

A series of comparative statistical analyses were conducted on the sheep/goat and cattle data to determine the presence of any significant differences in the frequency of different aetiologies for each species (Table 9.49). With the exception of oral pathology and mixed lesions, the rest of the aetiology categories were analysed using chi-square. Arthropathy and congenital were the only two to display a significant difference at $\alpha = 0.05$, the strongest result seen in the arthropathy category. It is clear from the data presented that cattle displayed a high frequency of arthropathy compared to sheep/goat; however, by comparing this in context with the overall NISP counts for each species, this difference has been proven to be statistically significant and not a product of differing NISP ratios. The analyses

comparing non-specific bone proliferation and non-specific bone lysis for both cattle and sheep/goat were not significant at α= 0.05.

Table 9.49 X^2 results: cattle and sheep/goat aetiologies

Aetiology (cattle vs. sheep/goat)	$X^2_{(1)}$	*P* value	H_0 Accept or reject?
Trauma	.04	.8472	Accept
Arthropathy	104.92	.0000	**Reject**
Congenital	5.66	.0174	**Reject**
Non-specific bone proliferation	.02	.8831	Accept
Non-specific bone lysis	.04	.8472	Accept
Sheep/goat: Non-specific bone proliferation vs. non-specific bone lysis	3.25	.0716	Accept
Cattle: Non-specific bone proliferation vs. non-specific bone lysis	1.00	.3168	Accept
Other (specifically, osteochondrosis manifesta)	1.03	.3111	Accept

Evidence for possible infection and differential diagnosis

A number of the pathological lesions recorded may potentially indicate the presence of infection. These include those categorised as non-specific bone lysis and non-specific bone proliferation. Non-specific bone proliferation totalled 12% of the aetiologies. All of these cases were identified as periostosis and were identified most predominantly in the oral (mandible) region of the skeleton (Figure 9.136).

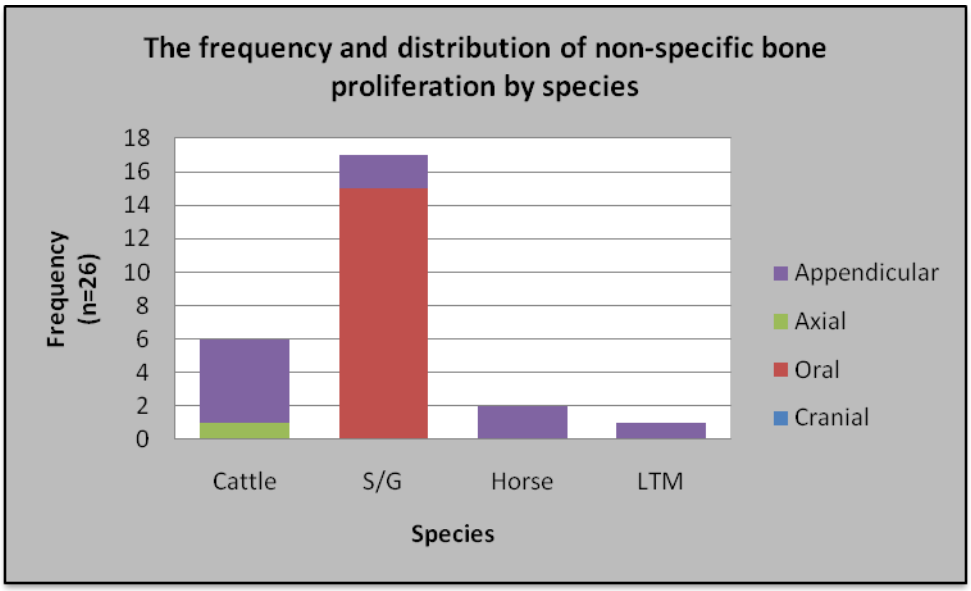
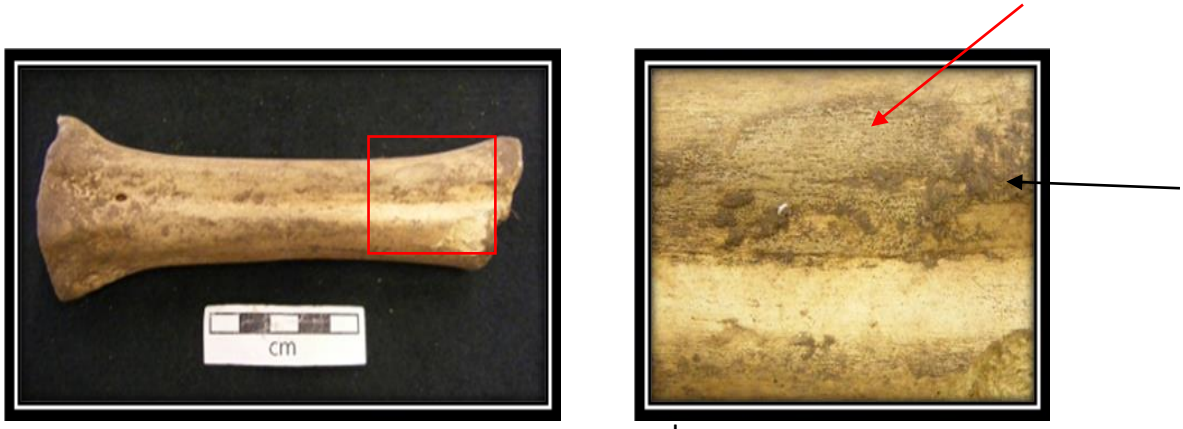


Figure 9.136 Non-specific bone proliferation by skeletal region at Hofstaðir

Lesions were identified in the oral, axial and appendicular skeletal regions, with the greater majority of non-specific bone proliferation (both woven and compact) identified on sheep/goat mandibles (n=15). The difference in lesion distribution throughout the skeleton is supported at $\alpha = 0.05$ ($X^2 = 24.15$, $p = .0000$, $p < 0.05$, d.f. = 3), illustrating that the pattern was not due to chance. The appendicular region was more frequently affected than the axial region. This pattern was also confirmed at $\alpha = 0.05$ ($X^2 = 7.36$, $p = .0066$, $p < 0.05$, d.f. = 1). These localised plaques are probably associated with periodontal disease and infection, although a number may also be a response to trauma. Two examples were located on the ascending ramus and may have been associated with trauma or stress to the tempero-mandibular joint. Both mandibles displayed abnormality within this region, with one exhibiting osteophyte formation around the margins of the joint and the second displaying a fissure/cleft on the surface of the joint. The latter is likely to be congenital/non-

pathological (see Baker and Brothwell 1980), and therefore may not be associated with the periostosis.

Nine cases of periostosis were also recorded on the appendicular skeleton of cattle, sheep/goat, horse and LTM. The periostosis largely consisted of localised plaques of compact new bone formation suggesting a healed condition at death. (Figure 9.137).



a b

Figure 9.137 Cattle metatarsal displaying localised periostosis located on the cranial distal diaphysis (a). Close-up view of the periostosis (b) (red arrow), black arrow also highlights adhering soil, which in some cases may be misidentified as periostosis (Photo: Author)

These examples of periostosis may possess a number of different aetiologies: non-specific infection, periodontal disease, trauma, neoplasia and metabolic/nutritional deficiency. The localised nature of the compact plaques of new bone would potentially indicate either resolved trauma or infection.

Non-specific bone lysis totalled 5% of the pathological lesion types. These comprised porous, lytic lesions (55%), pitting/porosity (18%), space-occupying lesions (9%), cystic lesions (9%), and an enlarged foramen (9%) (Figure 9. 138). The axial and appendicular regions were affected with the axial region favoured, however, there was no significant difference identified at α = 0.05 (X^2 = .818, p= .3657, p > 0.05, d.f. = 1).

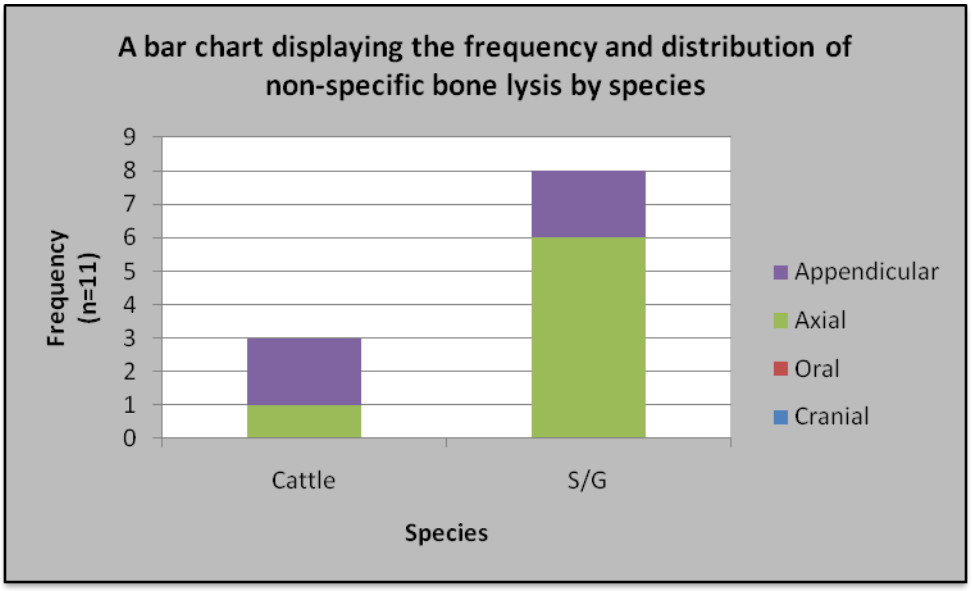
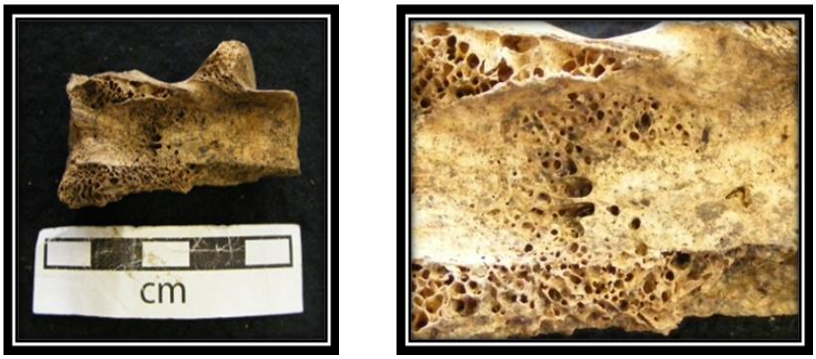


Figure 9.138 Non-specific bone lysis by skeletal region at Hofstaðir

Porous, lytic lesions were the most frequent type of non-specific bone lysis recorded (55%). All six cases were observed on sheep/goat vertebrae (5 x axis vertebrae, 1 x atlas vertebrae) (Figure 9.139). This bone loss may be related to infection, nutritional deficiency, metabolic disorder or osteoporosis.



a b

Figure 9.139 Sheep/goat axis (a) displaying a porous, lytic lesion with exposure of the trabecular bone (b) (Photo: Author)

A cystic lesion was recorded on a cattle second phalanx and a perforating, space-occupying lesion was recorded on a sheep/goat metatarsal (Figure 9.140).

a b

Figure 9.140 Sheep/goat metatarsal (a) with a perforating lesion in the proximal articular surface (b) (Photo: Author)

At first glance, the latter resembles a perforation associated with bone marrow extraction; however, upon closer inspection the margins of the lesions are smooth. There is no new bone formation associated with this lesion and no obvious associated swelling of the diaphysis (osteitis). Therefore, this may represent a congenital malformation as opposed to an infective process. The cystic lesion observed on the articular surface of the cattle phalanx is probably associated with

arthropathy as the phalanx also possessed osteophyte formation around the proximal epiphysis. Therefore, this lesion may represent a small sub-chrondral cyst. Two cases of pitting/porosity were observed in the proximal epiphyses of a sheep/goat and cattle metatarsal. These isolated cases may be related to minor trauma, infection/inflammation or arthropathy.

Summary

The assemblage at Hofstaðir totalled 109,373 fragments. The identifiable fragments associated with the three main Viking Age phases were analysed. Two hundred and twenty types of pathology were recorded on 188 bones, equating to less than 1% of the entire assemblage. Sheep/goat was the most frequently affected species (71%), followed by cattle (25%). However, there was no significant difference between the frequency of palaeopathology for these species at $\alpha = 0.05$. However, statistically significant differences were noted between these two species for the arthropathy and congenital aetiology categories. There were a number of bones exhibiting both non-specific bone proliferation and bone lysis, possibly indicative of infection. A significant difference was highlighted in the distribution of non-specific bone proliferation throughout the skeleton, with the mandible most frequently affected. The greater frequency of lesions located in the appendicular region as opposed to the axial region was also statistically supported at $\alpha = 0.05$. Non-specific bone lysis lesions were identified in the axial and appendicular regions, however, there was no significant difference identified at $\alpha = 0.05$. No bones from Hofstaðir were sampled for aDNA.

9.10 Sveigakot, Mývatnssveit, Iceland

The faunal assemblage recovered from the excavations at Sveigakot was selected alongside that from Hofstaðir (section 9.9) and Hrísheimar (section 9.11). The primary reason for targeting this assemblage was the fact that it is associated with a *landnám* settlement and as such, some of the faunal remains may represent livestock introduced from Scandinavia. If pathological, these remains could potentially represent the introduction of disease to Iceland. In addition to this, the assemblage provides a comparison to the nearby and contemporary Hrísheimar and the later Hofstaðir.

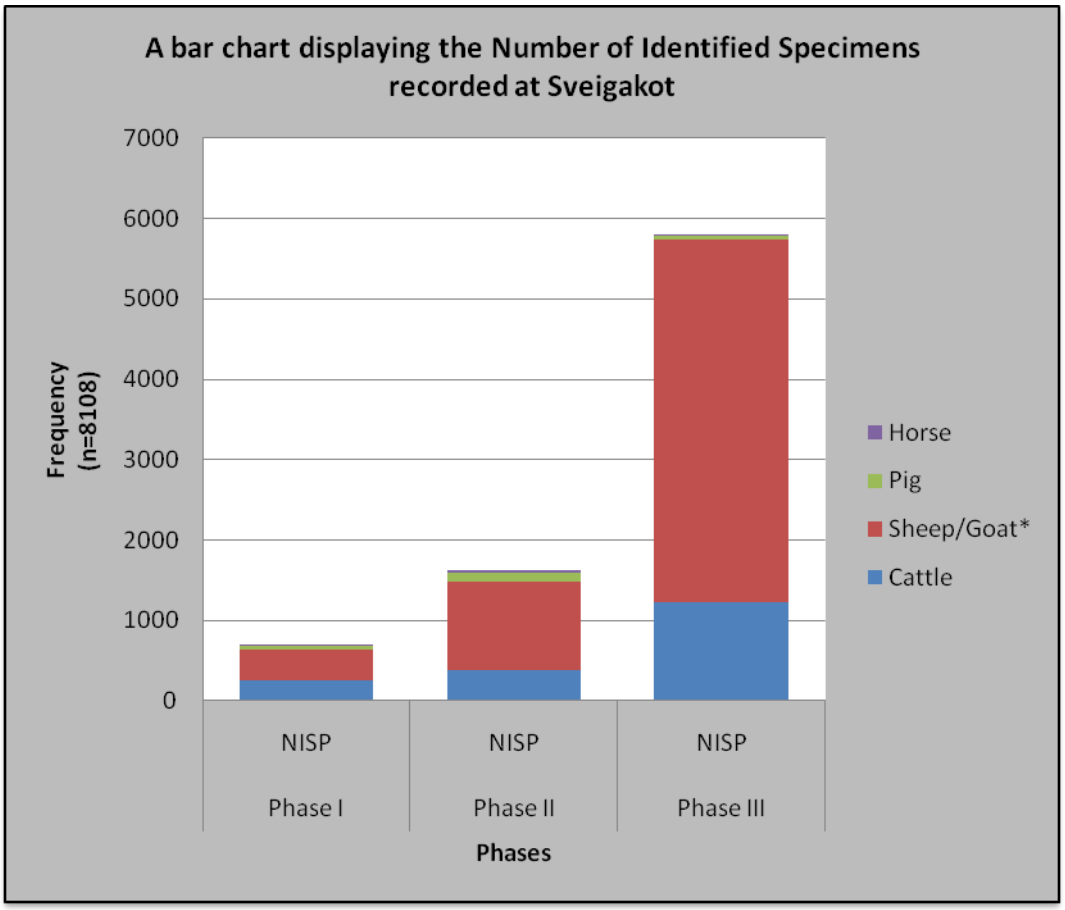
9.10.1 The Disarticulated Assemblage

The disarticulated assemblage was analysed, recorded and reported on by researchers at the Brooklyn College and Hunter College Zooarchaeology Laboratories, City University of New York (CUNY) (McGovern *et al.* 2004). The assemblage was largely recovered from substantial midden deposits and totals 37,732 fragments (section 6.7.3). The chronology of the site is split into three main phases dating from the late 9th to the late 12th centuries. As with Hofstaðir, the majority of the assemblage, particularly the quantifiable material, is housed in the Hunter Laboratory; the un-quantifiable fragments were returned to Iceland prior to the present researcher's visit. As a result of this, only the quantifiable material associated with the domestic mammal species and dating to one of the three Viking Age phases was recorded (Table 9.50, Figure 9.141).

Table 9.50 Number of Identified Specimens at Sveigakot: Domestic species (Data taken from McGovern *et al.* 2004: Tables 5 & 7)

Domestic Species	**Phase I**		**Phase II**		**Phase III**	
	NISP	***%NISP***	**NISP**	***%NISP***	**NISP**	***%NISP***
Cattle	246	*36*	374	*23*	1220	*21*
Sheep/Goat	329	*48*	991	*61*	4216	*73*
Sheep	42	*6*	100	*6*	286	*5*
Goat	15	*2*	15	*1*	22	-
Pig	55	*8*	121	*7*	46	*1*
Horse	1	-	21	*1*	8	-
TOTAL No. IDENTIFIED	**688**	**-**	**1622**	**-**	**5798**	**-**
LTM	123	-	485	-	782	-
MTM	456	-	1707	-	3615	-
STM	-	-	7	-	22	-
Unidentified	2574	-	5517	-	7897	-
TOTAL No. UNIDENTIFIED	**3153**	**-**	**7716**	**-**	**12316**	**-**
TNF (Domestic species + unidentified)	**3841**	**-**	**9338**	**-**	**18114**	**-**

Key: Large Terrestrial Mammals (LTM); Medium Terrestrial Mammals (MTM); Small Terrestrial Mammals (STM)



***sheep/goat includes separate sheep and goat identifications**

Figure 9.141 Number of Identified Specimens recorded at Sveigakot

Palaeopathology

One hundred and fifty-five types of pathology were recorded on 95 bones, equating to less than 1% of the entire assemblage. Sheep/goat dominated the domestic species identifications, in addition to being the most frequent species identified as pathological (82% - including one definite goat). Cattle followed with 12% (Figure 9.142). The low frequency of pathological LTM and MTM fragments is a reflection of absence of the non-quantifiable fragments. The frequency of palaeopathological

bones differed markedly between sheep/goat and cattle. This difference was statistically significant at α = 0.05 (X^2 = 5.17, *p*=.0230, p < 0.05, d.f. = 1).

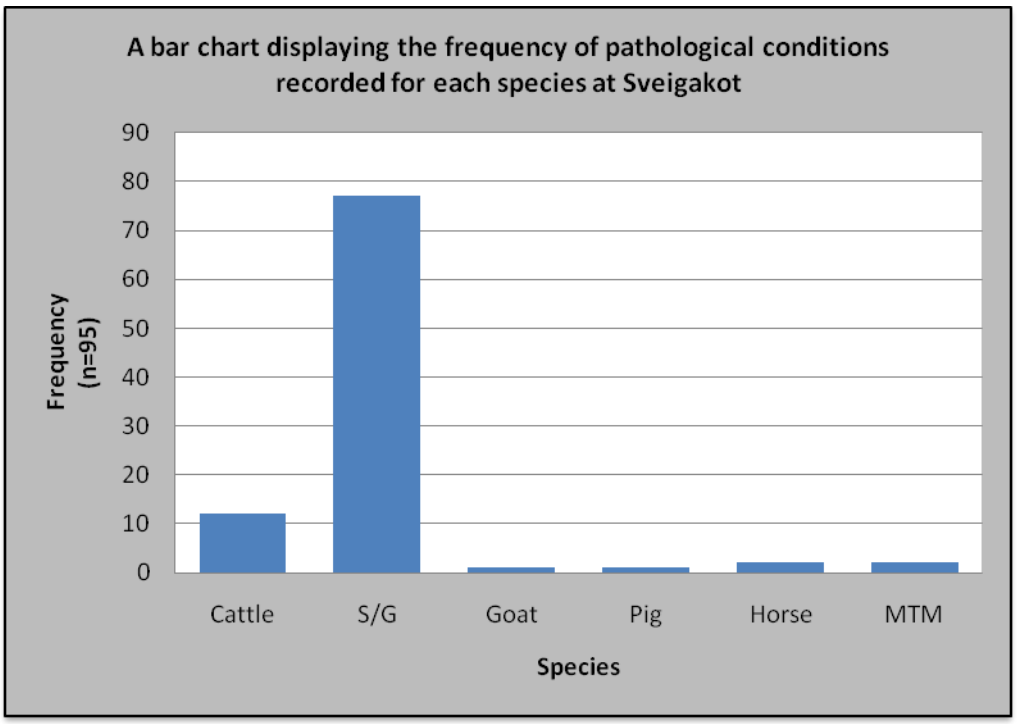


Figure 9.142 The frequency of pathological conditions recorded by species at Sveigakot

A summary of palaeopathological lesion types

Table 9.51 and Figure 9.143 illustrate the frequency of pathological conditions by species for the assemblage at Westness. Abnormal bone lysis (47%) represents the most frequent lesion type, followed in equal measure by abnormal bone proliferation (25%) and other (25%). Mixed lesions, abnormal bone shape and abnormal bone size, when combined represent 3%. Lesions associated with osteochondrosis manifesta (55%) dominate the abnormal bone lysis lesion type, followed by alveolar recession (23%), porous, lytic lesions (7%), pitting/porosity (7%), cortical cleft (possibly non-pathological) (3%), fissure (3%) and a cystic lesion

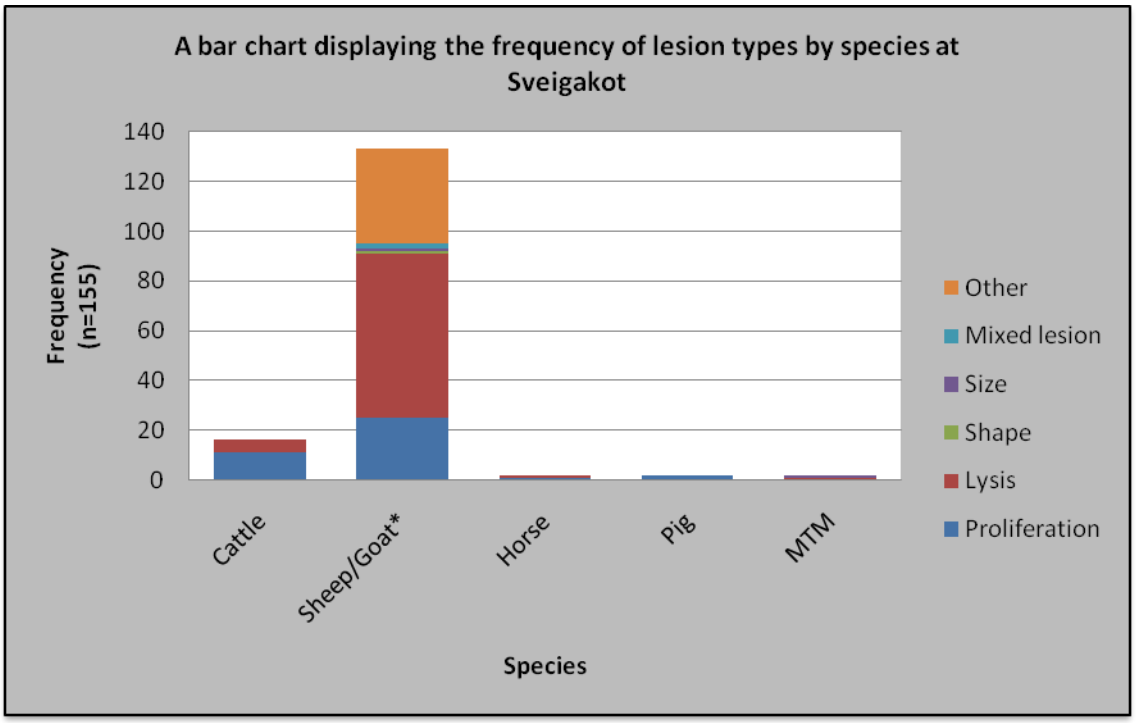
(1%). Periostosis (44%) dominated the abnormal bone proliferation lesion types, followed by osteophyte formation (36%), enthesophyte formation (15%), and ankylosis (5%).

Table 9.51 Sveigakot: Summary of pathological lesion types by species

Species Affected	Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed lesion	Other
Cattle	11	5	-	-	-	-
Sheep/Goat*	25	66	1	1	2	38
Horse	1	1	-	-	-	-
Pig	2	-	-	-	-	-
MTM	-	1	-	1	-	-
TOTAL No.	**39**	**73**	**1**	**2**	**2**	**38**
TOTAL %	**25**	**47**	**1**	**1**	**1**	**25**

***includes 1 x goat**

The two mixed lesion cases both involved multiple lesions associated with trauma. The single case of abnormal bone shape involved a dysplastic sheep/goat mandible following ante-mortem tooth loss. The two cases of abnormal bone size case were associated with an enlarged foramen in a MTM lumbar vertebra and widening of the alveolus in a sheep/goat mandible. The 'other' category included: abnormal attrition (34%), ante-mortem tooth loss (29%), malocclusion (21%), pulp cavity exposure (PCE) (5%), tooth misalignment (5%), hypercementosis of the tooth roots (3%) and calculus (3%).



*** includes 1 x goat**

Figure 9.143 The frequency of lesion types by species at Sveigakot

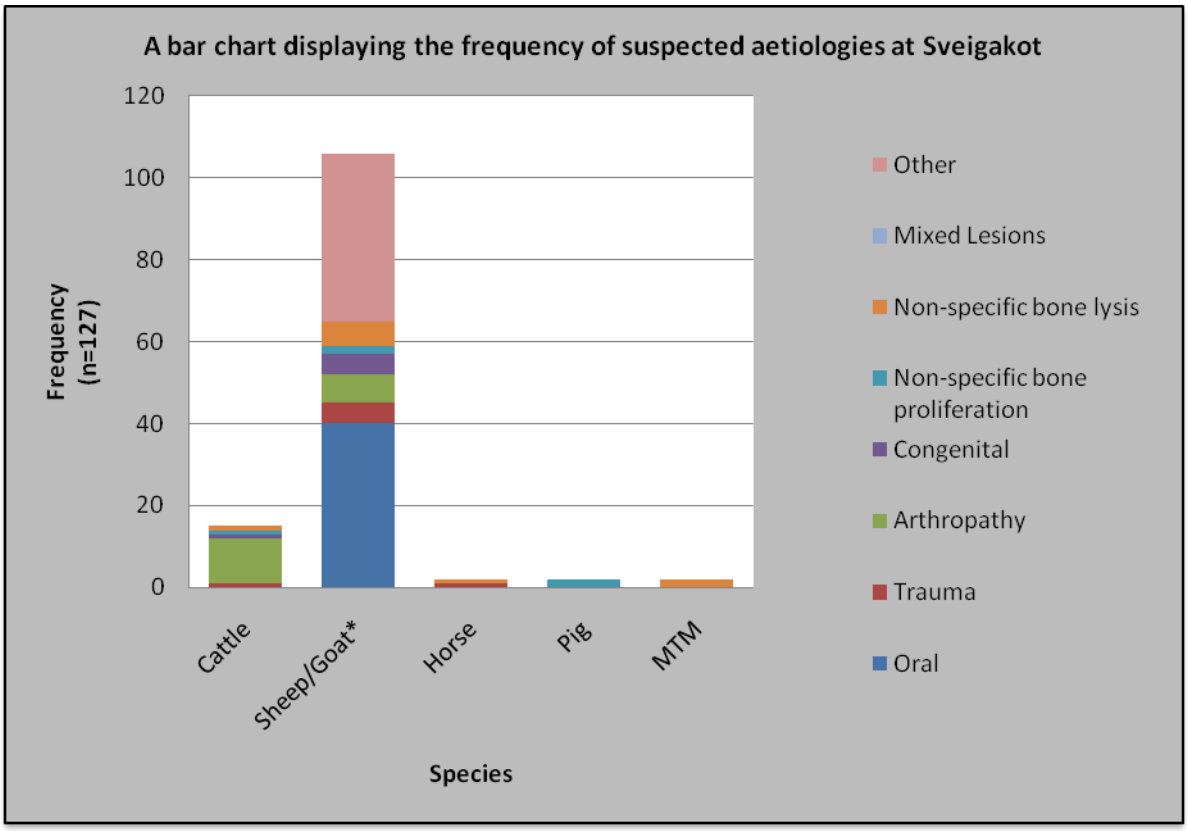
A summary of palaeopathological lesion characteristics: suspected aetiologies

Table 9.52 and Figure 9.144 illustrate the frequency of pathological conditions recorded by specie at Hofstaðir. Other was the most frequent category (32%), followed by oral pathology (31%), arthropathy (14%), non-specific bone lysis (8%), trauma (5%), congenital (5%) and non-specific bone proliferation (4%).

Table 9.52 Sveigakot: Summary of aetiologies by species

Species Affected	General Aetiology Categories							
	Oral	Trauma	Arthropathy	Congenital	Infection?		Mixed lesions	Other
					Non-specific bone proliferation	Non-specific bone lysis		
Cattle	-	1	11	1	1	1	-	-
Sheep/Goat*	40	5	7	5	2	6	-	41
Horse	-	1	-	-	-	1	-	-
Pig	-	-	-	-	2	-	-	-
MTM	-	-	-	-	-	2	-	-
TOTAL No.	**40**	**7**	**18**	**6**	**5**	**10**	**-**	**41**
TOTAL %	**31**	**5**	**14**	**5**	**4**	**8**	**-**	**32**

***includes 1 x goat**



***includes 1 x goat**

Figure 9.144 The frequency of suspected aetiologies recorded by species at Sveigakot

A series of comparative statistical analyses were conducted on the sheep/goat and cattle data to determine the presence of any significant differences in the frequency of different aetiologies for each species (Table 9.53). With the exception of oral pathology, mixed lesions and other, the rest of the aetiology categories were analysed using chi-square. Arthropathy was the only aetiology to display a statistically significant difference at $\alpha = 0.05$. The data only supported the intraspecies analysis of sheep/goat for non-specific bone proliferation and non-specific bone lysis. The resulting chi-square and p value was not significant at $\alpha = 0.05$.

Table 9.53 X^2 results: cattle and sheep/goat aetiologies

Aetiology (cattle vs. sheep/goat)	$X^2_{(1)}$	*P* value	H_0 Accept or reject?
Trauma	.15	.6959	Accept
Arthropathy	14.29	.0002	**Reject**
Congenital	.15	.6959	Accept
Non-specific bone proliferation	.16	.6852	Accept
Non-specific bone lysis	.33	.5680	Accept
Sheep/goat: Non-specific bone proliferation vs. non-specific bone lysis	1.29	.2567	Accept

Evidence for possible infection and differential diagnosis

A number of the pathological lesions recorded may potentially indicate the presence of infection. These include those categorised as non-specific bone lysis and non-specific bone proliferation. Five cases of periostosis were recorded affecting cattle, sheep/goat and pig. Lesions were identified in the appendicular and oral regions of the skeleton (Figure 9.145). Unfortunately, there was not enough data to compare the skeletal distribution of these lesions.

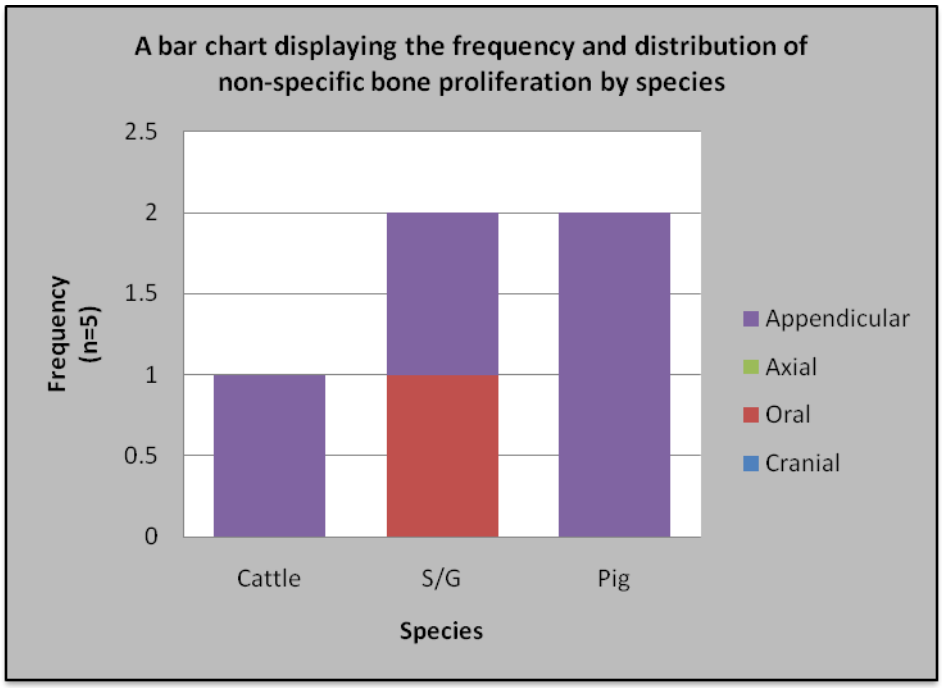
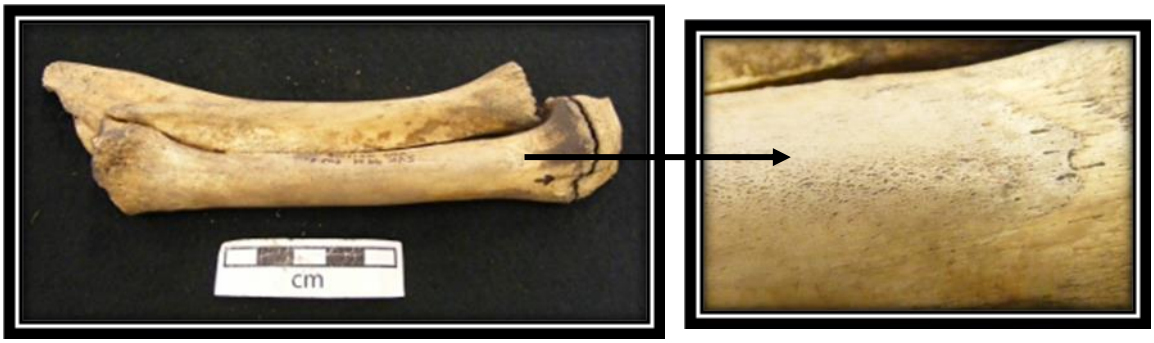


Figure 9.145 Non-specific bone proliferation by skeletal region at Sveigakot

The periostosis consisted of localised plaques of both woven and compact new bone formation, suggesting both active and healed conditions at death (Figure 9.146). Periostosis affecting the appendicular skeleton may be associated with systemic infection, localised osteomyelitic infection, localised trauma, neoplasia or metabolic/nutritional deficiency. Periostosis affecting the mandible may be associated with localised trauma, periodontal disease and localised infection – possibly an abscess. In this example, a sheep/goat mandible displayed periostosis localised to the alveolar bone. This location would strongly suggest periodontal disease and/or irritation of the gums (gingivitis).



a b

Figure 9.146 Pig radius and ulna (a), displaying localised plaque of compact new bone on the lateral aspect of the distal diaphysis (b) (Photo: Author)

Non-specific bone lysis totalled 8% of the suspected aetiologies. These comprised porous, lytic lesions (70%), pitting/porosity (20%) and enlarged foramen (10%) (Figure 9.147). The lesions were identified in the appendicular and axial regions, with the axial region most frequently affected. However, this difference was not supported at $\alpha = 0.05$ ($X^2 = 3.60$, p=.0577, $p > 0.05$, d.f. = 1).

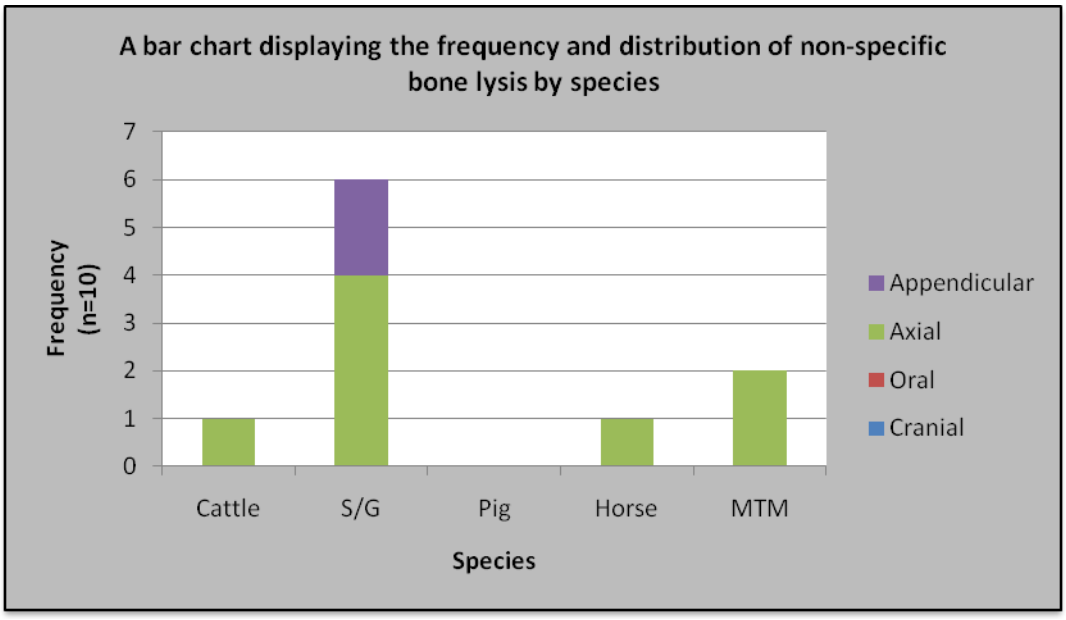
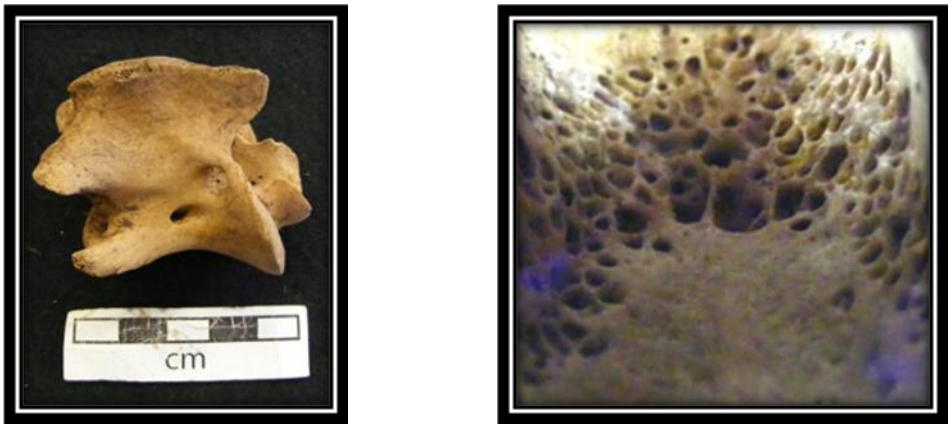


Figure 9.147 Non-specific bone lysis by skeletal region at Sveigakot

Porous, lytic lesions were the most frequent type of non-specific bone lysis recorded (70%). Seven cases were recorded affecting sheep/goat, horse, cattle and LTM. Six of these involved vertebrae (Figure 9.148), with the remaining case involving a sternum fragment (Figure 9.149).



a b

Figure 9.148 Sheep/goat axis (a), with porous, lytic lesion within the vertebral foramen exposing the trabecular bone (b) (Photo: Author)

a b

Figure 9.149 Horse sternum with localised porous, lytic lesion (a). Close-up view illustrates exposure of the trabecular bone (b) (Photo: Author)

The loss of bone within the vertebral foramen of the sheep/goat axis may be related to infection involving the blood vessels, nutritional deficiency, metabolic disorder or osteoporosis. The latter is not considered likely as the rest of the bone was in a good and structurally stable condition. The area of bone loss affecting the sternum is localised, measuring c.1cm in diameter. The bone has been subject to butchering with the fragment chopped cranially-caudally. There are also some fine cut marks (not displayed in Figure 9.149). This localised lesion may represent direct transfer of an infective process from a soft tissue focus or infected lymph node. Actinomycosis can involve the sternum though direct extension of reticulitis (section 4.2.2). However, this could also represent a nutritional deficiency, metabolic disorder or even be the beginning of osteoporosis. Two cases of pitting/porosity were observed in the proximal epiphyses of two sheep/goat metatarsals. These isolated cases of bone loss may be related to minor trauma, infection, arthropathy or age-related. As the joint is affected, it could represent joint stress or be an early sign of arthropathy or infection. A small lytic lesion resembling osteochrondrosis was also noted in the articular surface of one of the

latter sheep/goat metatarsals. This may represent arthropathy or just reflect a minor cortical bone defect.

Summary

The faunal assemblage from Sveigakot totalled 37,732 fragments. As with Hofstaðir, only the quantifiable material associated with the domestic mammal species dating to one of the three Viking Age phases was recorded. One hundred and fifty-five types of pathology were recorded on 95 bones, equating to less than 1% of the entire assemblage. The greater majority of sheep/goat bones analysed were identified as pathological (82%), compared to only 12% of cattle bones. This difference was statistically significant at $\alpha = 0.05$ ($X^2 = 5.17$, p=.0230, $p < 0.05$, d.f. = 1). There were a number of bones exhibiting both non-specific bone proliferation and bone lysis, possibly indicative of infection. Non-specific bone lysis lesions were identified in the appendicular and axial regions, with the axial region most frequently affected. However, this difference was not supported at $\alpha = 0.05$. No bones from Sveigakot were sampled for aDNA.

9.11 Hrísheimar, Mývatnssveit, Iceland

The faunal assemblage recovered from the excavations at Hrísheimar was selected alongside Hofstaðir (section 9.9) and Sveigakot (section 9.10). As with Sveigakot, Hrísheimar was selected because it represents another *landnám* settlement and provides the potential to analyse the introduction of diseased livestock from Scandinavia. The assemblage also provides a comparative dataset to the nearby and contemporary Sveigakot and the later Hofstaðir.

9.11.1 The Disarticulated Assemblage

The disarticulated assemblage is still in the process of being recorded and is curated at the Brooklyn College and Hunter College Zooarchaeology Laboratories, City University of New York (CUNY) (McGovern *et al.* 2005). The faunal remains from the 2001, 2004 and 2006 excavations were available for analysis; however, only those remains recovered during the 2001-2004 excavations have been reported on by McGovern *et al.* (2005). This report provides an indication of the species ratios associated with specific contexts from areas H and L. These contexts are dateable through their location in relation to the Veiðivötn tephra layer dating to c. 930AD and are presented in Table 9.54 and Figure 9.150. Although the full assemblage has yet to be recorded, the preliminary data regarding these specific contexts provided by McGovern *et al.* (2005) provide a basic idea of the species ratios associated with this site and how they compare with the nearby sites of Hofstaðir and Sveigakot . The assemblage at present is c. 27,780 bone fragments. However, the fact that the

assemblage was not fully analysed at the time of the present researcher's visit precludes statistical analyses because the data is not representative.

Table 9.54 Number of Identified Specimens at Hrísheimar: Domestic species (Data taken from McGovern *et al.* 2005: Table 1)

Domestic Species	**Below c.950 tephra**		**Above c.950 tephra**	
	NISP	***%NISP***	**NISP**	***%NISP***
Cattle	107	*10*	264	*16*
Sheep/Goat	780	*74*	887	*53*
Sheep	159	*15*	139	*8*
Goat	3	-	22	*1*
Pig	3	-	344	*21*
Horse	1	-	5	-
TOTAL No. IDENTIFIED	**1053**	**-**	**1661**	**-**
LTM	134	-	361	-
MTM	1568	-	2745	-
STM	12	-	6	-
Unidentified	2385	-	14330	-
TOTAL No. UNIDENTIFIED	**4099**	**-**	**17442**	**-**
TNF (Domestic species + unidentified)	**5152**	**-**	**19103**	**-**

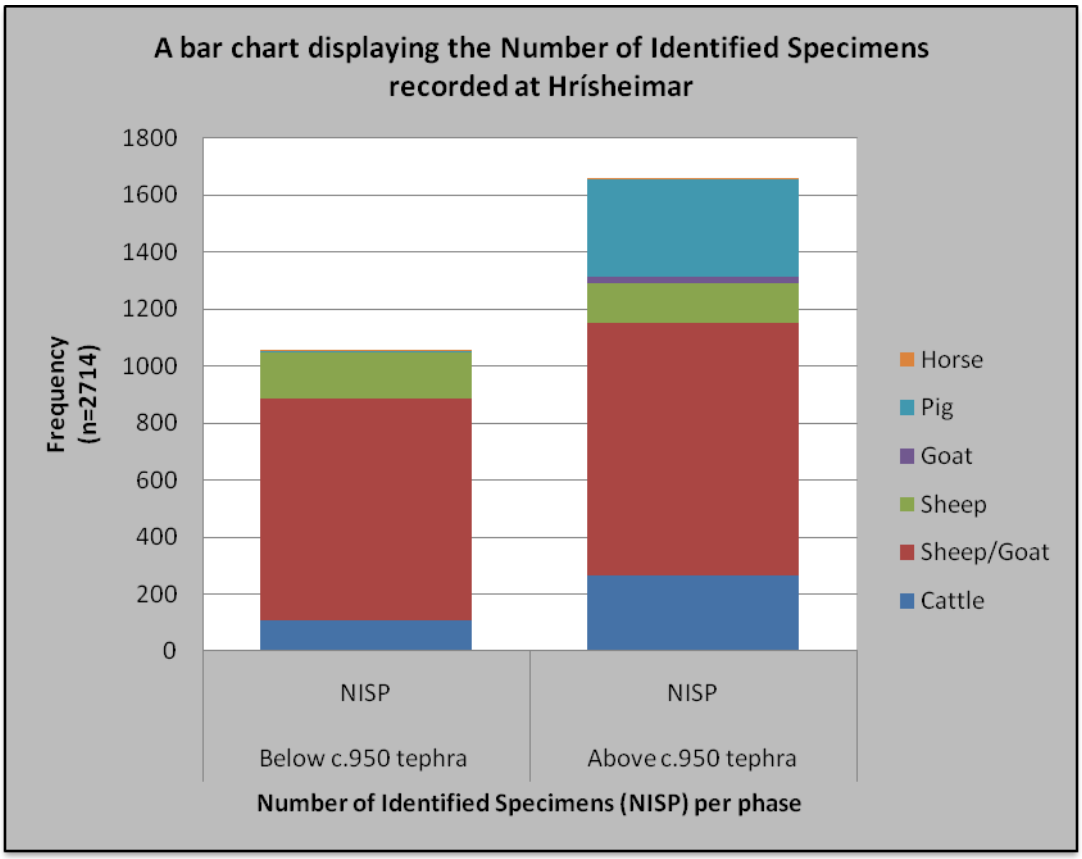


Figure 9.150 Number of Identified Specimens recorded at Hrísheimar

Palaeopathology

Sixty-two types of pathology were recorded on 44 bones, equating to less than 1% of the entire assemblage. Sheep/goat dominated the domestic species identifications, in addition to being the most frequent species identified as pathological (86% - including one definite goat).

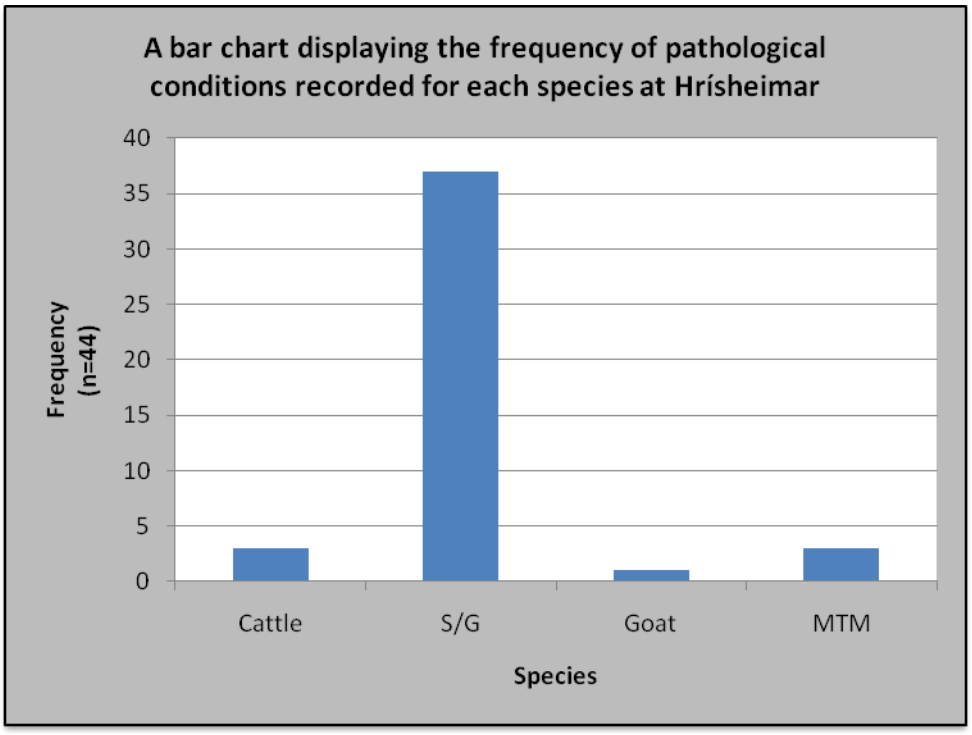


Figure 9.151 The frequency of pathological conditions recorded by species at Hrísheimar

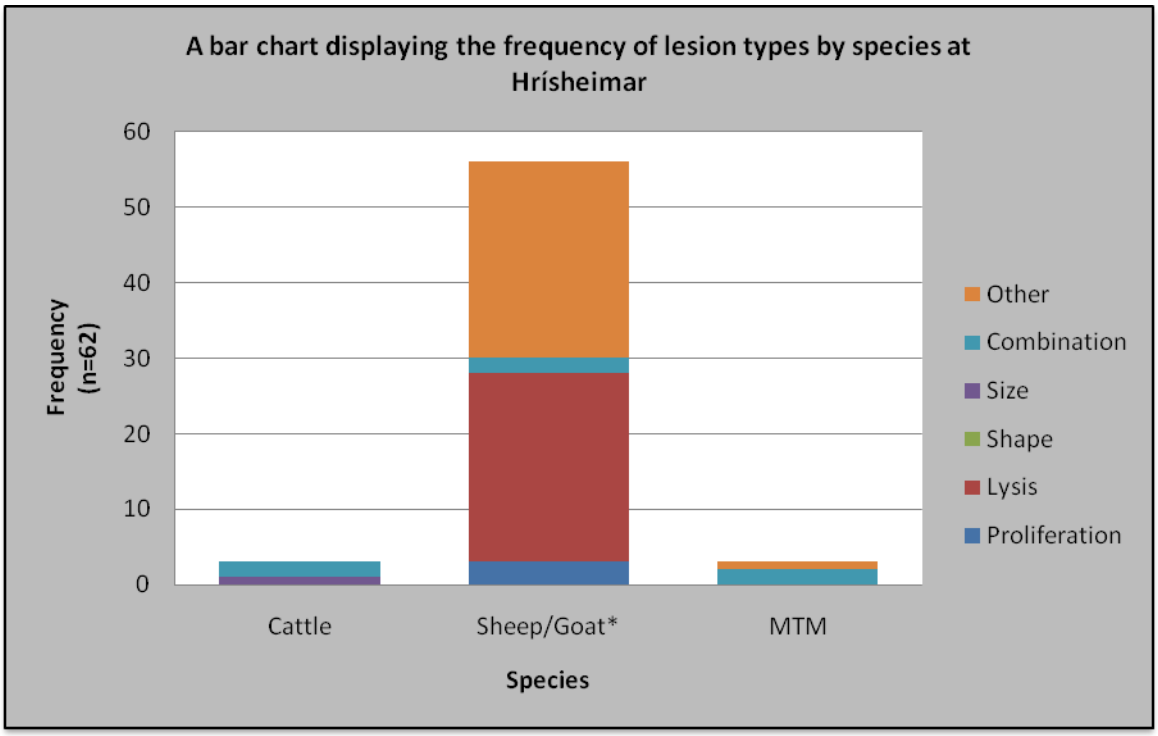
A summary of palaeopathological lesion types

Table 9.55 and Figure 9.152 illustrate the frequency of pathological conditions by species for the assemblage at Hrísheimar. The other category represents the most frequent lesion type recorded, followed by abnormal bone lysis (40%) mixed lesions (10%), abnormal bone proliferation (5%) and size (2%). Lesions associated with osteochondrosis manifesta (56%) dominate the bone lysis lesion types, followed by alveolar recession (28%), porous, lytic lesions (12%) and cortical cleft (possibly non-pathological) (4%). Periostosis comprised 33% of the abnormal bone formation lesion types, along with ankylosis (33%) and osteophyte formation (33%).

Table 9.55 Hrísheimar: Summary of pathological lesion types by species

Species Affected	Lesion Type					
	Proliferation	Lysis	Shape	Size	Mixed lesion	Other
Cattle	-	-	-	1	2	-
Sheep/Goat*	3	25	-	-	2	26
MTM	-	-	-	-	2	1
TOTAL No.	**3**	**25**	**-**	**1**	**6**	**27**
TOTAL %	**5**	**40**	**-**	**2**	**10**	**44**

***includes 1 x goat**



***includes 1 x goat**

Figure 9.152 The frequency of lesion types by species at Hrísheimar

The six mixed lesion cases involved multiple lesions associated with trauma to a sheep/goat spinous process, arthropathy affecting a cattle femur, swollen MTM and sheep/goat spinous processes, a MTM rib with osteomyelitis and a cattle metapodia with both lytic and proliferative lesions affecting the distal shaft and condyle. The single case of abnormal bone size case was associated with an enlarged foramen in a cattle caudal vertebra.

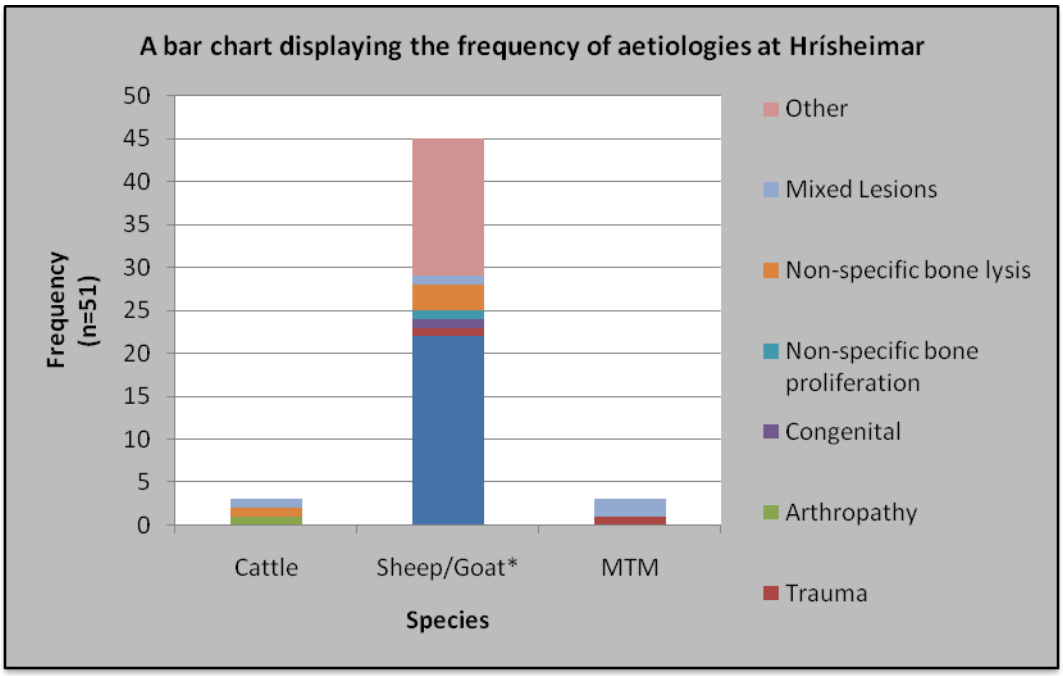
A summary of palaeopathological lesion characteristics: aetiologies

Table 9.56 and Figure 9.153 illustrate the frequency of pathological conditions recorded by species at Hrísheimar. Oral pathology was the most frequent category (43%), followed by other (31%), non-specific bone lysis (8%), mixed lesions (8%), trauma (4%), arthropathy (2%), non-specific bone proliferation (2%) and congenital (2%).

Table 9.56 Hrísheimar: Summary of aetiologies by species

Species Affected	General Aetiology Categories							
	Oral	Trauma	Arthropathy	Congenital	Infection?		Mixed lesion	Other
					Non-specific bone proliferation	Non-specific bone lysis		
Cattle	-	-	1	-	-	1	1	-
Sheep/Goat*	22	1	-	1	1	3	1	16
MTM	-	1	-	-	-	-	2	-
TOTAL No.	**22**	**2**	**1**	**1**	**1**	**4**	**4**	**16**
TOTAL %	**43**	**4**	**2**	**2**	**2**	**8**	**8**	**31**

***includes 1 x goat**



***i**

ncludes 1 x goat

Figure 9.153 The frequency of aetiologies recorded by species at Hrísheimar

Evidence for possible infection and differential diagnosis

A number of the pathological lesions recorded may potentially indicate the presence of infection. These include those categorised as non-specific bone lysis and non-specific bone proliferation. Non-specific bone lysis totalled 8% of the aetiologies. These comprised porous, lytic lesions (75%) and an enlarged foramen (25%) (Figure 9.154).

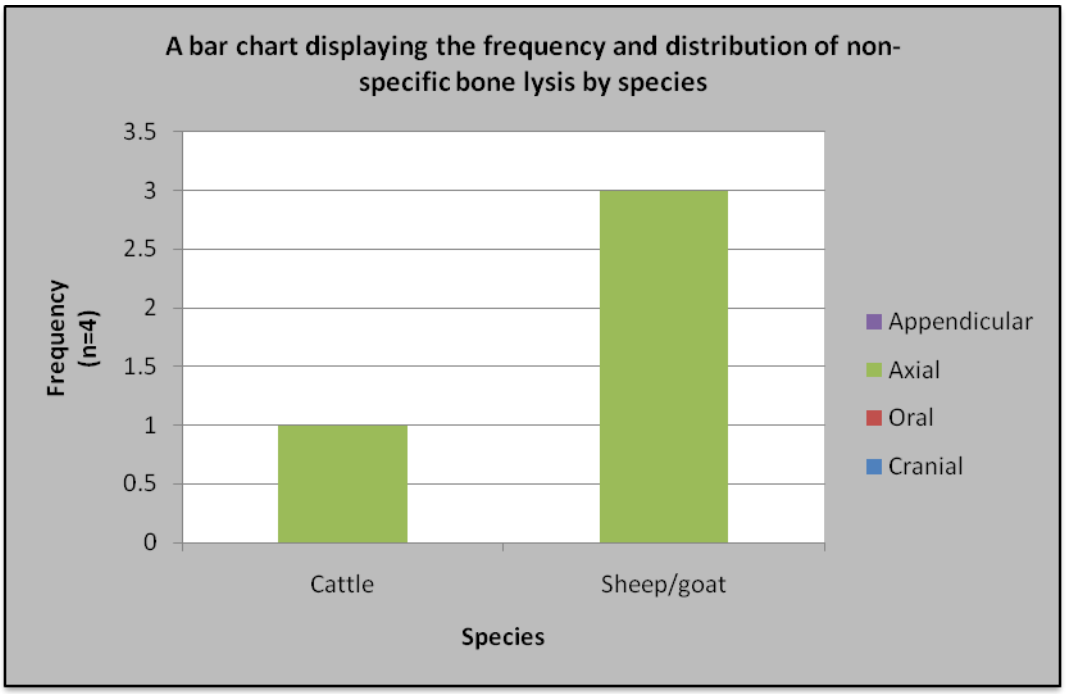


Figure 9.154 Non-specific bone lysis by skeletal region at Hrísheimar

Three cases of porous, lytic lesions were recorded affected a sheep/goat axis, cervical vertebra and sacrum. This bone loss may be related to infection involving the blood vessels, nutritional deficiency, metabolic disorder or osteoporosis. A single enlarged foramen was also identified on a cattle caudal vertebra (Figure 9.155). This example is very similar to a case observed at Wetwang Slack. The enlarged basi-vertebral foramina associated with the basi-vertebral vein is located within the vertebral foramen and others are found on the ventral aspect of the vertebral body. There is no associated new bone formation, but the radiograph does display very well-defined margins that appear sclerotic. There is the possibility that this represents a congenital or developmental anomaly, but the fact that it is visible both within the vertebral body and externally would suggest something else. This could indicate increased blood flow and widening of the blood vessels – possibly in association with infection.

a

b

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d

c

Figure 9.155 Cattle caudal vertebra (a) displaying enlarged basi-vertebral foramina on the ventral aspect of the vertebral body (b) and also within the vertebral foramen (c, d)(Photo: Author, X-ray: Dr. Jo. Buckberry)

A single case of periostosis was observed on a goat radius and ulna. This was compact but pitted and was associated with the fusion of the ulna shaft to the

caudal radius diaphysis. This point of fusion was proximal to the normal location and, therefore, may have been associated with trauma as opposed to infection.

There were also four mixed lesion cases that potentially reflect an infective origin. Two thoracic spinous processes (1 x MTM and 1 x sheep/goat) both display swelling and pitting close to the dorsal tips. These do not appear to be associated with trauma, but without a radiograph it is difficult to be certain. The swelling represents osteitis in both cases and possibly a localised infection. These examples, although very similar in morphology, were from separate contexts and are unlikely to belong to the same animal. A single space-occupying lesion was recorded on the distal condyle of a cattle metapodial in association with periostosis. A channel had formed through this new bone leading to the lytic lesion located just above the distal condyle. This may be an infective process, which may have progressed to destroying the larger parts of the distal condyle, or it could be trauma associated with traction. Similar new bone proliferation or exotoses also associated with channels have been reported on in traction animals (see Bartosiewicz *et al.* 1997). The last case involves a MTM rib displaying swelling and pitting of the neck and head region accompanied by two cloacae (Figure 9.156). The radiograph does not indicate an obvious fracture, ruling out infection following trauma. The combination of swelling, pitting and cloacae indicate osteomyelitis. Specific infections including MTB Complex and brucellosis require consideration, along with non-specific pyogenic osteomyelitis. Mycotic infections including coccidioidomycosis (section 4.4.1) and blastomycosis (section 4.4.2) also target the ribs and can result in osteomyelitis. This rib was sampled for aDNA analysis (section 9.12).

a

b

Removed due to copyright restrictions

c

d

e

Figure 9.156 An MTM rib with osteomyelitis in the neck and head region (a, c). Two cloacae are visible (a, e), along with swelling and microporosity (d) (Photo: Author, X-ray: Dr. Jo. Buckberry)

Summary

The faunal assemblage associated with Hrísheimar was not fully recorded at the time of the present researcher's visit, therefore, only a sample of bones were analysed. Preliminary analyses indicate that sheep/goat dominate the domestic species identifications. Sixty-two types of pathology were recorded on 44 bones,

equating to less than 1% of the entire assemblage. Sheep/goat bones were most frequently identified as pathological, comprising 86% of the palaeopathological observations. However, it was not possible to confirm this pattern statistically. There were a number of bones exhibiting both non-specific bone proliferation and bone lysis, possibly indicative of infection. A single MTM rib with osteomyelitis was sampled for aDNA (section 9.12).

9.12 The Biomolecular Results

In order to further explore those lesions identified as possessing a possible infectious aetiology, a number of bones were selected from ABGs and disarticulated assemblages for aDNA analysis. The aim was to investigate the potential of lesion specificity in relation to MTB complex disease. The selected bones were sent to Dr. G.M. Taylor, Centre for Clinical Microbiology, University College London (UCL) for sampling and analysis. The results of this analysis are presented below. A full report of the results authored by Dr. G.M. Taylor can be viewed in Appendix 3.

9.12.1 Modern Case Studies: The biomolecular results

In the early stages of this research, modern pathological ABGs with lesions possibly indicative of infection were targeted for analysis and DNA testing. This was in an attempt to establish some known lesion characteristics for MTB complex in skeletal material. A pig (section 9.41), two badgers (section 9.4.2 & 9.4.3) and a red deer (section 9.4.4) were tested. Three samples were initially positive for MTB complex pathogen DNA, however, they were not reproduced in the first test centre (UCL).

9.12.2 Wetwang Slack ABGs: The biomolecular results

Pathological bones possessing lesions suggestive of possible infection were selected for aDNA analysis based upon lesion morphology and lesion location. Five ABGs (two horses, two cattle and one pig) from Wetwang Slack were identified as possessing lesions suggestive of possible infection. The pathological lesions were directly sampled (Table 9.57, Table 9.58).

Table 9.57 Wetwang Slack ABG samples (after Taylor 2010: Table 1a with additions)

Sample No.	Species	Element	Context
JW1 (Jan)	Horse	Thoracic vertebra	WE 64 AR
JW2 (Jan)	Horse	Atlas vertebra	WE 66 AP
JW3 (Jan)	Cattle	Sternum	WE 8 AQ
JW4 (Jan)	Cattle	Rib	WE 81 BG
JW5 (Jan)	Pig	Rib	WS 342 MJ

Table 9.58 Wetwang Slack ABG samples, weight (after Taylor 2010: Table 1a with additions)

Sample No.	Species	Element	Context	Bone weight 1 (mg)	Bone weight 2 (mg)
JW1 (Jan)	Horse	Thoracic vertebra	WE 64 AR	110	80
JW2 (Jan)	Horse	Atlas vertebra	WE 66 AP	130	60
JW3 (Jan)	Cattle	Sternum	WE 8 AQ	40	20
JW4 (Jan)	Cattle	Rib	WE 81 BG	100	80
JW5 (Jan)	Pig	Rib	WS 342 MJ	70	40

All five samples from Wetwang Slack were negative for pathogen DNA associated with both MTB Complex and brucellosis (Table 9.59) (Taylor 2010, Appendix 3).

Table 9.59 Wetwang Slack ABG samples: biomolecular results demonstrating the absence of pathogen DNA, but the presence of mitochondrial DNA (mtDNA) in two samples (after Taylor 2010: Table 3, with additions).

Sample No.	Context	IS*1081* 135 bp	IS*1081* 113 bp	IS*1081* 79 bp	DR region PCRs 70 bp		Brucella 108 bp	*Cyt b* (mtDNA)
					FAM probe spacer 23	HEX probe spacer 38		
JW1	WE 64AR	-	-	-	-	-	-	-
JW2	WE 66AP	-	-	-	-	-	-	**+**[1]
JW3	WE 8AQ	-	-	-	-	-	-	**+***
JW4	WE 81BG	-	-	-	-	-	-	-
JW5	WS 342 MJ	-	-	-	-	-	-	-

* Confirmed by automated DNA sequencing.

[1] Not sequenced.

Even the smallest templates (70 bp) targeting spacers 23 and 38 in the DR region were negative (Figures 9.157 & 9.158). This would appear to indicate that the Wetwang Slack ABGs were not suffering from these diseases at death. However, there is the possibility that taphonomy and DNA degradation was an inhibiting factor.

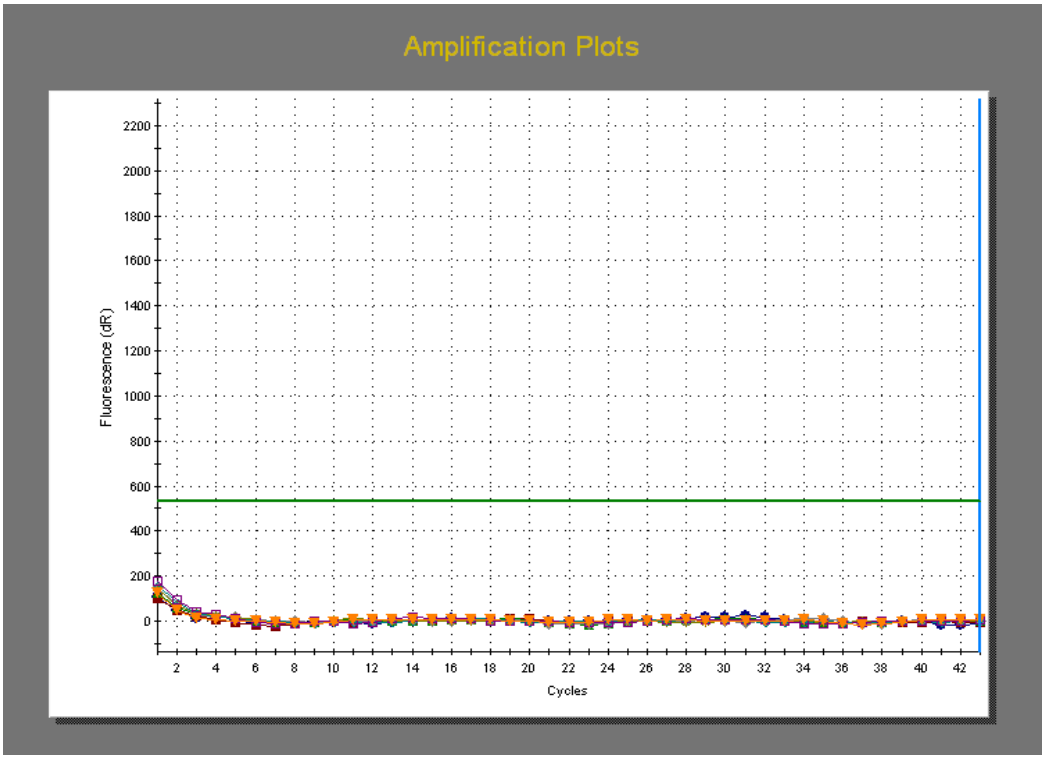

Figure 9.157 Real time PCR of the DR locus using the HEX probe targeting spacer 38 displaying consistently negative results for all five samples from Wetwang Slack (courtesy of Dr. G.M. Taylor)

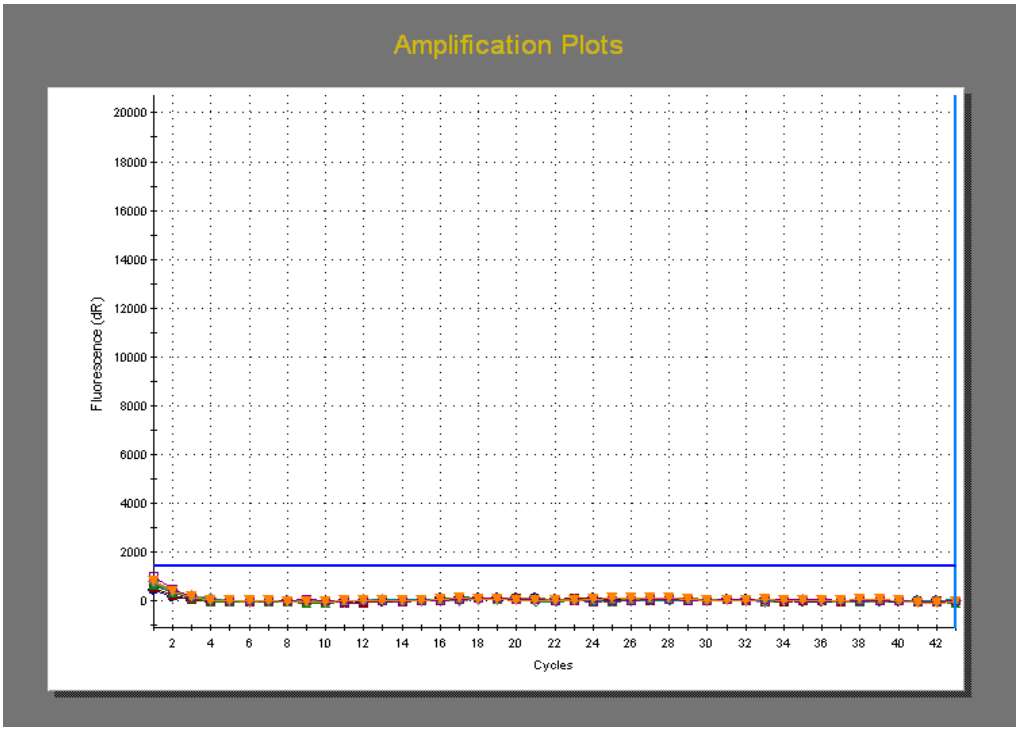

Figure 9.158 Real-time PCR for the DR locus using the FAM probe targeting spacer 23 displaying consistently negative results for all five samples from Wetwang Slack (courtesy of Dr. G.M. Taylor)

Mitochondrial DNA (mtDNA)

The amplification of mitochondrial DNA (mtDNA), specifically the species-specific cytochrome b (*cytb*) gene was slightly more successful. Samples from two horses (WE 64 AR & WE 66 AP) and one cattle bone sampled (WE 8 AQ) produced bands of the expected size (Figures 9.159 & 9.160). The product obtained from WE 8 AQ was confirmed through sequencing. The *cytb* products amplified from both horses sampled were not sequenced. Even though the gel electrophoresis produced bands of the expected size, they were unfortunately too weak for confirmation (Taylor 2010, see appendix 3). The successful amplification of mtDNA in some of the samples illustrates that the absence of MTB complex pathogen DNA cannot solely be attributed to DNA degradation and taphonomy at Wetwang Slack – however, it cannot be completely ruled out in the other cases where mtDNA was absent.

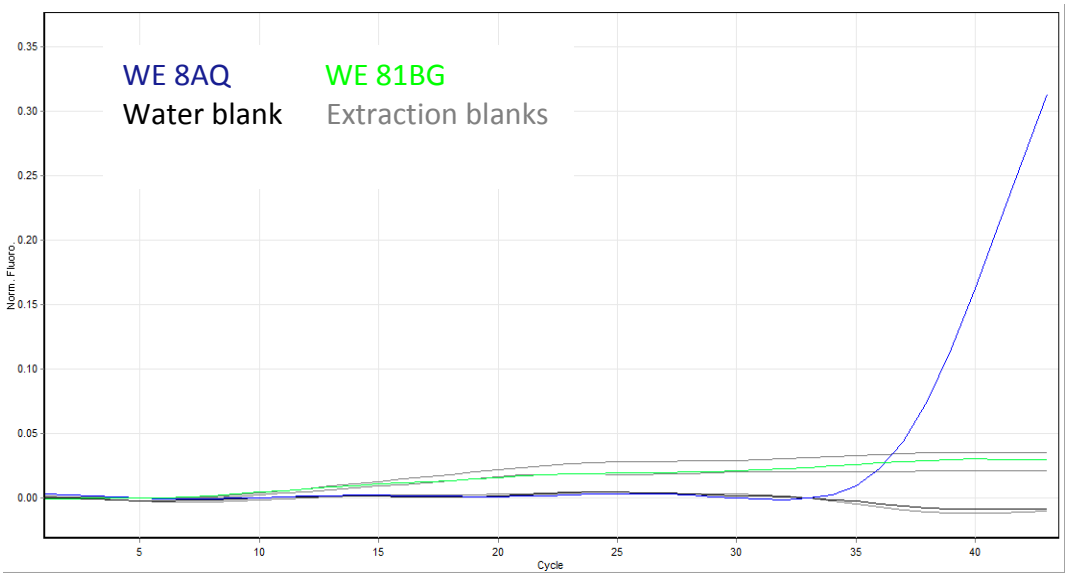

Figure 9.159 WE 8 AQ: Real-time PCR amplified with 124 bp primer set. Product formation followed with hydrolysis probe (Taylor 2010: Figure 1a)

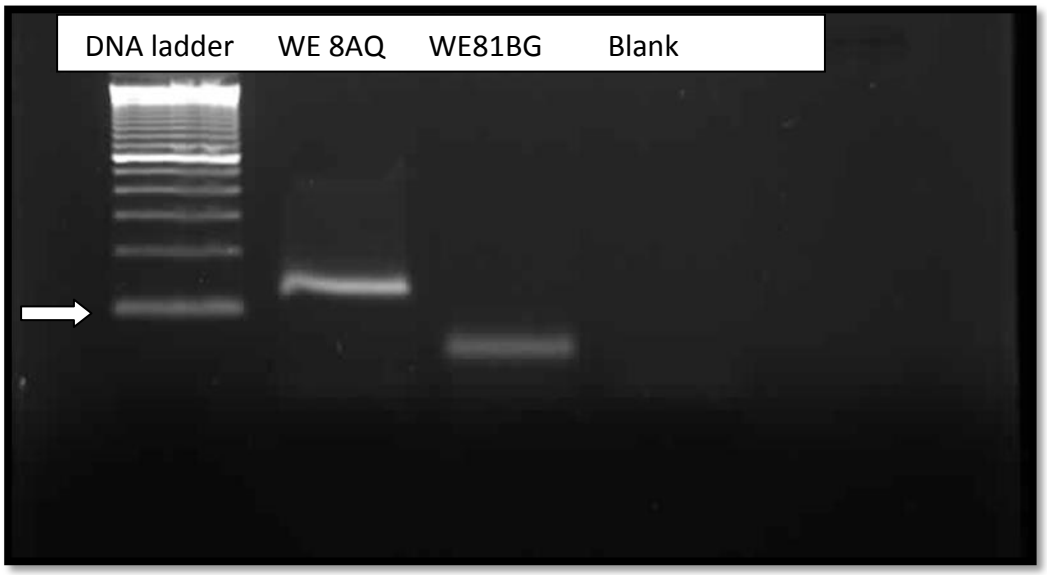

Figure 9.160 WE 8 AQ: Bulk purification of 124 bp *cytb* PCR product (see Figure 9.159). Arrow indicates 100 bp marker (Taylor 2010: Figure 1b)

9.12.3 Disarticulated samples: The biomolecular results

Samples from three disarticulated archaeological bones (two horse ribs and a medium terrestrial mammal (MTM) rib) and two disarticulated modern bones from the Baker Collection (pig scapula and horse rib) were also sampled (Table 9.60).

Table 9.60 Disarticulated archaeological and the Baker Collection samples (after Taylor 2010: Table 1b with additions)

Sample No.	Site	Species	Element	Context	Bone weight 1 (mg)
JW1 (May)	Barton field	Horse	Rib	A VI FII	40
JW2 (May)	Baker Collection	Horse	Rib	1030	40
JW3 (May)	Hrisheimer	MTM	Rib	HRH'04, 39	40
JW4 (May)	Baker Collection	Pig	Scapula	1046	40
JW5 (May)	Danebury Hillfort	Horse	Skull & Atlas	DA 82, P2148	40
JW6 (May)	Danebury Hillfort	P1153	Lumbar vertebra	DA 79, P1153	40

The six samples were screened for both Brucella and MTB complex pathogen DNA. In order to target MTB complex DNA, IS*1081* methods designed to target 135 and 113 base pairs (bp) were employed. All the samples screened for Brucella DNA were negative. The MTM rib from Hrisheimer did produce a band of the expected size for *brucella*, but this was unable to be sequenced. The initial tests for MTB complex

DNA were negative and a refined method targeting smaller numbers of base pairs (79bp) was designed by Dr. G.M. Taylor and applied to the samples again. On this occasion, four of the six were positive (Table 9.61, Figure 9.161). These four included both the Baker Collection modern bones and two archaeological bones from Barton Field, Tarrant Hinton and Danebury Hillfort (Taylor 2010: Appendix 3)

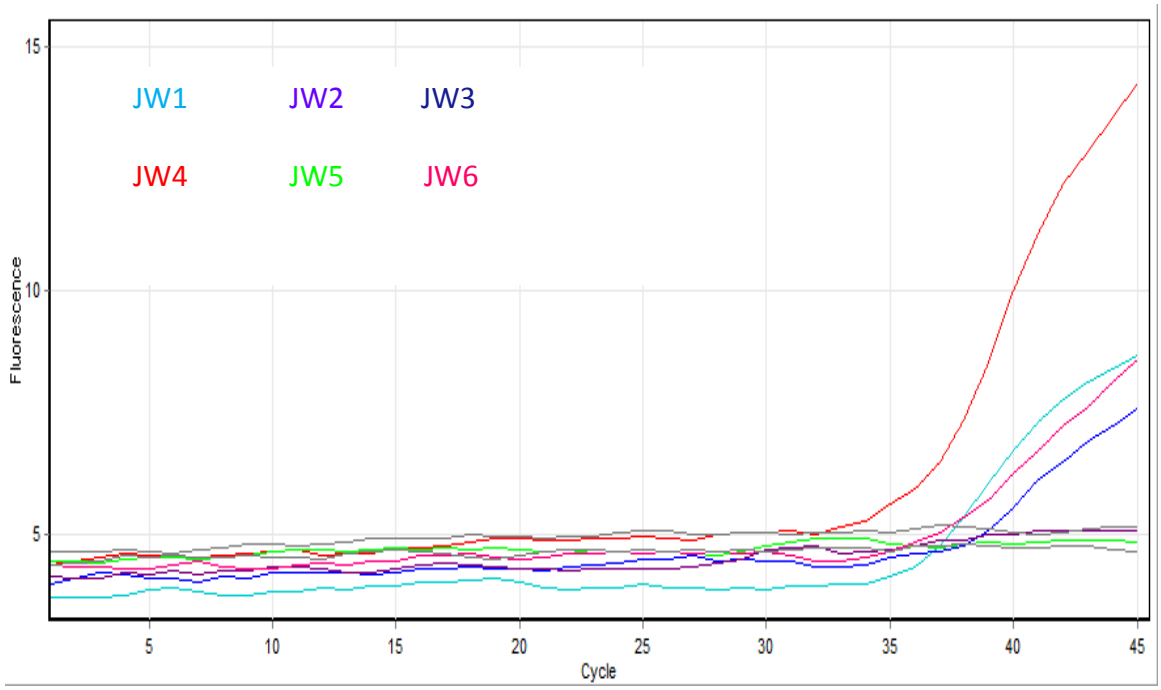

Figure 9.161 Real-time PCR for the IS*1081* locus using the HEX probe (Taylor 2010: figure 4 with additions)

Table 9.61 Disarticulated archaeological samples and the Baker Collection: biomolecular results demonstrating amplification of pathogen DNA, species-specific DNA and mtDNA (after Taylor 2010: Table 4, with additions)

Sample No.	Site/ Assemblage	Context	IS*1081* 135 bp	IS*1081* 113 bp	IS*1081* 79 bp	DR region PCRs 70 bp		Brucella 108 bp	*Cyt b*
						FAM probe spacer 23	HEX probe spacer 38		
JW1 (May)	Barton Field, Tarrant Hinton	A VI FII	-	-	+	+	-	-	+*
JW2 (May)	Baker Collection	1030	-	-	+	+	+	-	+*
JW3 (May)	Hrisheimer	39	-	-	-	+	-	100 bp Band[2]	-
JW4 (May)	Baker Collection	1046	-	-	+	+	-	-	+[2]
JW5 (May)	Danebury Hillfort	P2148	-	-	-	+	-	-	+[2]
JW6 (May)	Danebury Hillfort	P1153	-	-	+	+	+	-	+[2]

* Confirmed by automated DNA sequencing, [2] Sequencing failed

All six cases were positive when further tests targeting the DR region were performed. The most successful results were associated with the spacer 23 FAM probe (Figure 9.162).

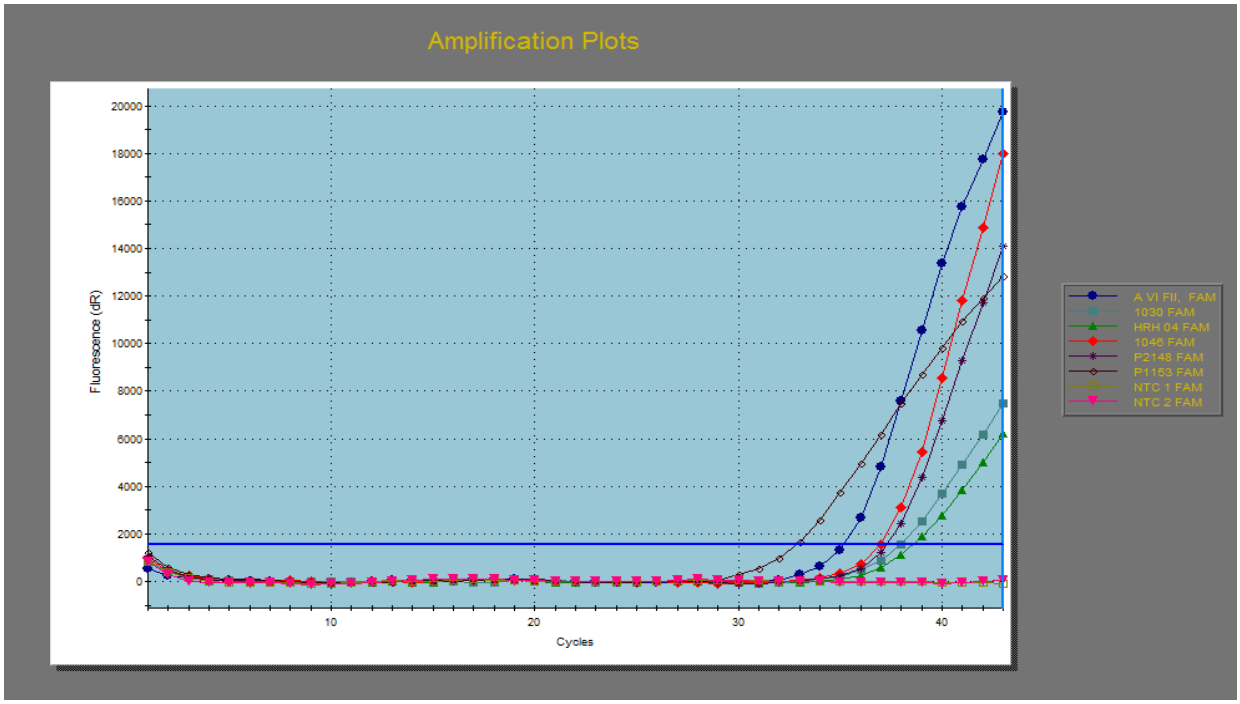

Figure 9.162 Real-time PCR for the DR locus using the FAM probe targeting spacer 23. The amplification plot displays positive results for all six samples (Taylor 2010: Figure 3)

The spacer 38 HEX probe was positive in just two cases, one modern and one archaeological (Figure 9.163). When the results of the FAM and HEX probes are amalgamated, the two bones that were positive at both spacers 23 and 38 were JW2 (Baker Collection horse rib) and JW6 (Danebury Hillfort LTM lumbar vertebra).

As a result, these two bones provide the most compelling evidence for the presence of MTB complex DNA in these bones (Taylor 2010: Appendix 3).

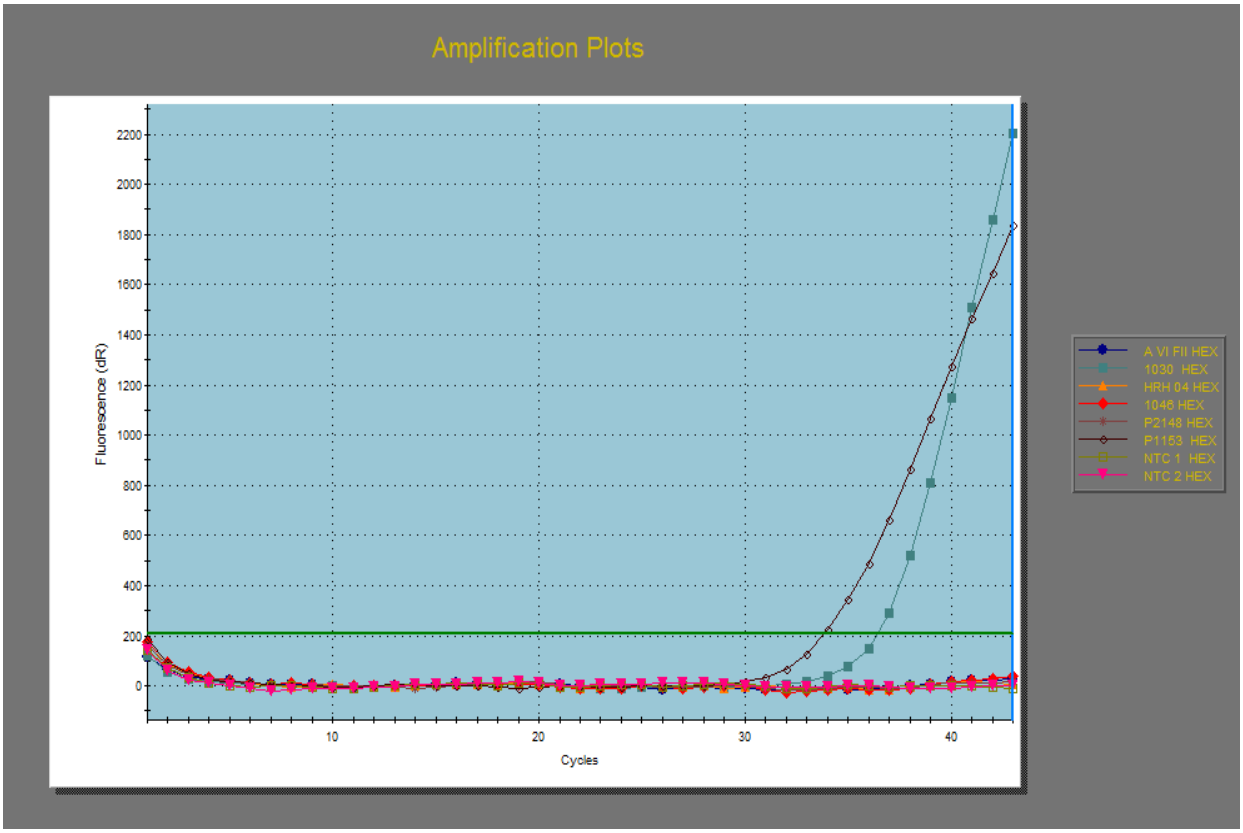

Figure 9.163 Real-time PCR for the DR locus using the HEX probe targeting spacer 38. The amplification plot displays two positive results for JW2 and JW6 (Taylor 2010: Figure 4)

Mitochondrial DNA (mtDNA)

The amplification of mitochondrial DNA (mtDNA), specifically the species specific cytochrome b (*cytb*) gene, was successful in two cases: a horse rib from Barton Field, Tarrant Hinton (JW1) and a modern horse rib from the Baker Collection (JW2)

(Figure 9.164). Equine mtDNA was confirmed through sequencing (Taylor 2010, see appendix 3).

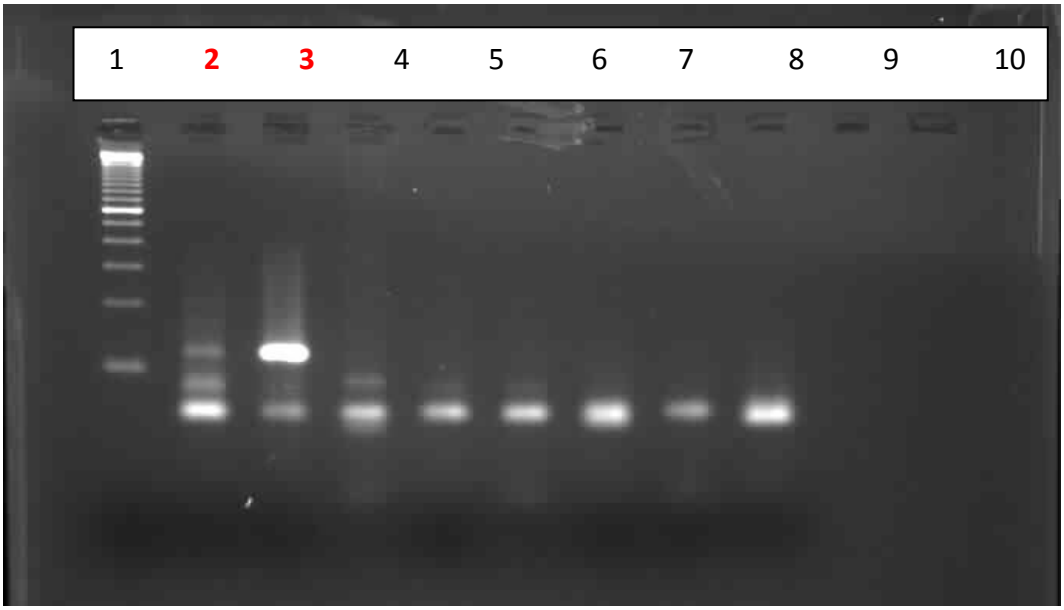

Figure 9.164 Gel electrophoresis on 3% agarose (Taylor 2010: Appendix 3, with additions)

Lane 1: 100 bp DNA size markers
Lane 2: JW1
Lane 3: JW2
Lane 4: JW3
Lane 5: JW5
Lane 6: JW6
Lane 7: JW7
Lanes 8 & 9: template blanks

Spoligotyping

The six samples were subjected to spoligotyping and all exhibited some of the expected 43 spacers. Samples JW2 and JW6 displayed the highest number with JW6, the large terrestrial mammal (LTM) lumbar vertebra from Danebury Hillfort, possessing a nearly complete fingerprint (Taylor 2010: Appendix 3).

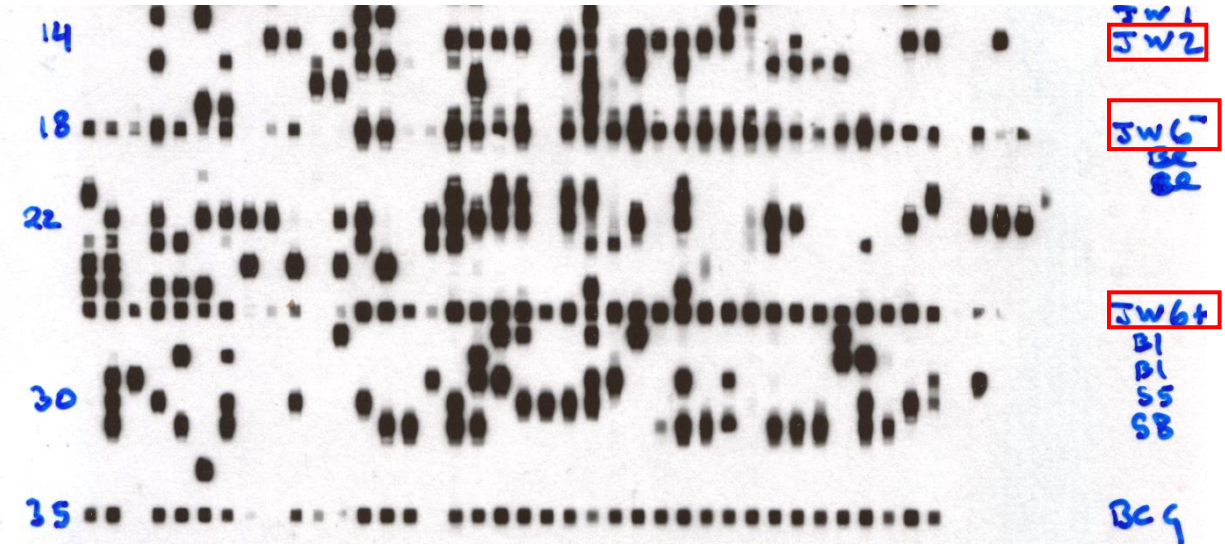

Figure 9.165 Spoligotyping of JW1-JW6 samples run with (+) and without (-) BSA in the PCR reaction mix. Samples JW2 and JW6 (with and without BSA) are highlighted. JW6 displays a near complete fingerprint when compared to BCG illustrating good preservation of the pathogen aDNA (Taylor 2010: Appendix 3).

Replication

Fresh samples were taken from the six bones positive in preliminary analysis at UCL. These were sent to Dr. G. Stewart, Department of Microbial Sciences, University of Surrey, for replication. The analysis is currently underway and the results pending.

9.13 Palaeopathology results: Inter-site comparisons

The following sections compare the cattle and sheep/goat palaeopathological results for two Iron Age/Romano-British sites (Wetwang Slack and Barton Field) and two Viking Age/Norse sites (Hofstaðir and Sveigakot). Inter and intra-species analyses are conducted for each site, ending with a comparison of species and time periods. The aim of these analyses is to highlight any significant differences in the frequency of aetiologies between species, sites and two specific periods in time.

9.13.1 Iron Age/Romano-British: Wetwang Slack vs. Barton Field

Sheep/goat dominated the NISP counts at both Wetwang Slack and Barton Field, followed by cattle and pig. This ratio of species fits into the general pattern observed for the Iron Age/early Romano-British period in southern Britain (see Hambleton 1999). Sheep/goat and cattle were the most frequently observed as displaying pathological change at both sites. There was no significant difference in the frequency of cattle palaeopathology at Wetwang Slack and Barton Field (X^2 = 2.88, p = .0895, p > 0.05, d.f. = 1). However, there was a significant difference in the frequency of sheep/goat palaeopathology (X^2 = 5.25, p = .0219, p < 0.05, d.f. = 1), with Wetwang Slack displaying a much greater preponderance of lesions in the bones of this species. The aetiology data for sheep/goat and cattle is presented in Figure 9.166.

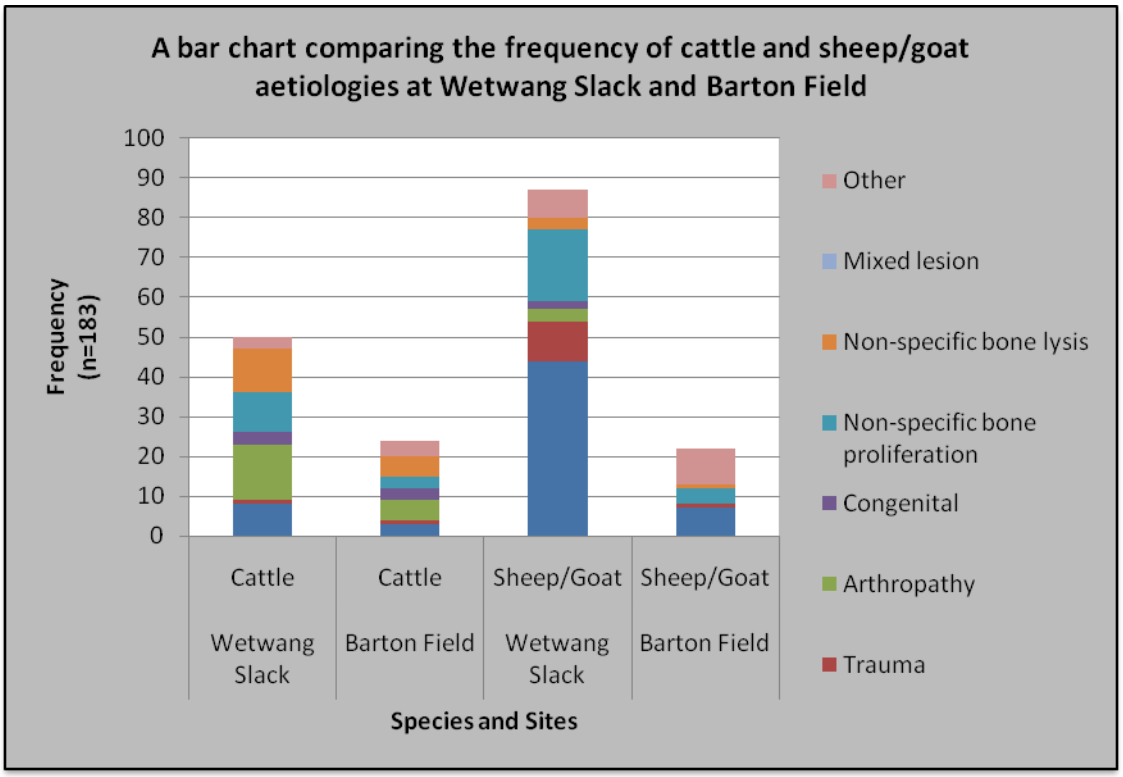

Figure 9.166 A comparison of cattle and sheep/goat aetiologies at Wetwang Slack and Barton Field

The proportions of aetiologies appear broadly similar for cattle at both sites, but there are some obvious differences associated with sheep/goat. At Wetwang Slack, there appears to be a higher frequency of both oral pathology and trauma. To test these differences, those aetiology categories possessing enough data for comparative analyses were statistically tested using a two sample chi-square test. The results of these comparative analyses are presented in Tables 9.62 & 9.63.

Table 9.62 X^2 results and *p* value: cattle vs. cattle aetiologies at Wetwang Slack and Barton Field

Iron Age/Romano-British Aetiologies (cattle vs. cattle)	$X^2_{(1)}$	*P* value	H_0 Accept or reject?
Oral pathology	.17	.6825	Accept
Arthropathy	.19	.6613	Accept
Non-specific bone proliferation	.01	.9370	Accept
Non-specific bone lysis	.77	.3790	Accept
Other (osteochondrosis manifesta)	.92	.3363	Accept

Table 9.63 X^2 results and *p* value: sheep/goat vs. sheep/goat aetiologies at Wetwang Slack and Barton Field

Iron Age/Romano-British Aetiologies (sheep/goat vs. sheep/goat)	$X^2_{(1)}$	*P* value	H_0 Accept or reject?
Oral pathology	6.42	.0113	**Reject**
Trauma	2.26	.1324	Accept
Non-specific bone proliferation	1.43	.2316	Accept
Non-specific bone lysis	.04	.8335	Accept
Other (osteochondrosis manifesta)	4.38	.0365	**Reject**

There were no significant differences identified in the cattle comparative analyses at Wetwang Slack and Barton Field (Table 9.62). These results support the observation of similar proportions displayed in Figure 9.166 for this species at both sites. For sheep/goat, significant differences were associated with oral pathology and lesions associated with *osteochondrosis manifesta* (OCM). The greater

frequency of oral pathology at Wetwang Slack is supported at α = 0.05. The chi-square results also support a greater frequency of OCM at Barton Field. The seemingly greater frequency of trauma at Wetwang Slack is not supported by the statistical analysis and is thus more likely a reflection of sample size.

9.13.2 Inter-species analysis: Cattle vs. sheep/goat

Comparative inter-species analyses were also conducted, focusing on the identification of any palaeopathological differences in cattle vs. sheep/goat in the Iron Age/Romano-British results. There is a significant difference in the frequency of palaeopathological lesions between the two species at α = 0.05 (X^2 = 5.62, p = .0177, p < 0.05, d.f. = 1).This was further explored through the comparison of all aetiology categories/pathological lesion types. The cattle and sheep/goat data from Wetwang Slack and Barton Field was combined to emphasise any potential patterns between the two species (Table 9.64).

Table 9.64 X^2 results and p value: Iron Age/Romano-British cattle vs. sheep/goat aetiologies

Iron Age/Romano-British Aetiologies (cattle vs. sheep/goat)	$X^2_{(1)}$	*P* value	H_0 Accept or reject?
Oral pathology	5.38	.0204	**Reject**
Trauma	1.54	.2154	Accept
Arthropathy	31.20	.0000	**Reject**
Congenital	7.12	.0076	**Reject**
Non-specific bone proliferation	.56	.4536	Accept
Non-specific bone lysis	22.17	.0000	**Reject**
Other (osteochondrosis manifesta)	.75	.3849	Accept

Significant differences were noted at α = 0.05 between cattle and sheep/goat for the following aetiology categories: oral pathology, arthropathy, congenital and non-specific bone lysis. This supports the greater frequency of oral pathology evident in sheep/goat and the greater frequency of arthropathy, congenital and non-specific bone lysis recorded in cattle.

9.13.3 Viking Age/Norse: Hofstaðir vs. Sveigakot

Sheep/goat also dominated the NISP counts at Hofstaðir and Sveigakot, followed in frequency by cattle, with pig represented in much smaller quantities. This ratio of species fits into the general pattern observed for the Viking Age/Norse in Iceland (see McGovern *et al.* 2007, Amarosi 1996). Sheep/goat and cattle were the most frequently observed species displaying pathological change at both sites. The aetiology data is presented in Figure 9.167. It is immediately obvious that there is a greater volume of data associated with Hofstaðir. The assemblage associated with this site was very large by comparison with Sveigakot. It was important to ascertain whether any differences evident in the palaeopathology data between the species and sites were real or a reflection of sample size. A series of two sample chi-square tests were conducted. The observed frequencies of cattle palaeopathology at Hofstaðir was compared with cattle at Sveigakot and there was a highly significant difference identified at α = 0.05 (X^2 = 16.52, p = .0000, p < 0.05, d.f. = 1). A significant difference was also identified when sheep/goat were compared at both sites (X^2 = 11.57, p = .0007, p < 0.05, d.f. = 1). This substantiates the differences in palaeopathology frequency for these two species and supports the statistical significance of the higher frequency observed at Hofstaðir.

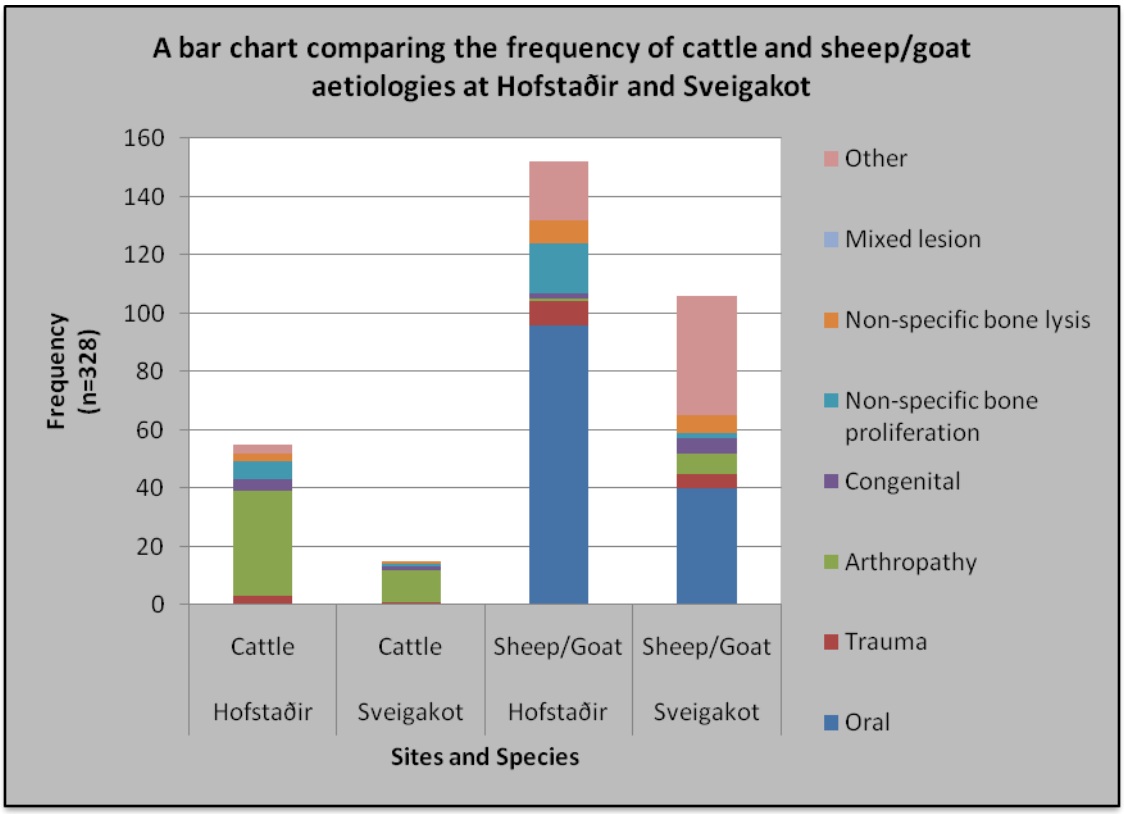

Figure 9.167 A comparison of cattle and sheep/goat aetiologies at Hofstaðir and Sveigakot

As in the Iron Age/Romano-British results, the proportions of aetiologies appear broadly similar for cattle at both sites. However, there are some differences associated with sheep/goat. At Hofstaðir, there appears to be a higher frequency of non-specific bone proliferation and oral pathology and a lower frequency of arthropathy and congenital conditions by comparison with Sveigakot. To test these apparent intra-species differences, those aetiology categories possessing enough data for comparative analyses were statistically tested. The results are presented in Tables 9.65 & 9.66.

Table 9.65 X^2 results and *p* value: cattle vs. cattle aetiologies at Hofstaðir and Sveigakot

Viking Age/Norse Aetiologies (cattle vs. cattle)	$X^2_{(1)}$	*P* value	H_0 Accept or reject?
Oral pathology	.75	.3876	Accept
Arthropathy	10.23	.0014	**Reject**
Congenital	1.42	.2339	Accept
Non-specific bone lysis	.75	.3876	Accept
Non-specific bone proliferation	2.93	.0869	Accept

Table 9.66 X^2 results and *p* value: sheep/goat vs. sheep/goat aetiologies at Hofstaðir and Sveigakot

Viking Age/Norse Aetiologies (sheep/goat vs. sheep/goat)	$X^2_{(1)}$	*P value*	H_0 Accept or reject?
Oral pathology	19.79	.0000	**Reject**
Trauma	.51	.4745	Accept
Arthropathy	4.91	.0267	**Reject**
Congenital	1.49	.2220	Accept
Non-specific bone proliferation	10.91	.0010	**Reject**
Non-specific bone lysis	.17	.6797	Accept
Other (osteochondrosis manifesta)	11.24	.0008	**Reject**

There was only one significant difference identified in the cattle comparative analyses between Hofstaðir and Sveigakot. This was associated with arthropathy and would appear to support the greater frequency of this aetiology at Hofstaðir. For sheep/goat, there were several significant differences noted between the two sites. These were associated with oral pathology, arthropathy, non-specific bone proliferation and lesions associated with *osteochondrosis manifesta* (OCM). The results support the greater frequency of oral pathology and non-specific bone proliferation observed at Hofstaðir at $\alpha = 0.05$. This verifies that these results were not associated with the larger faunal assemblage at this site. The higher frequency of arthropathy and OCM is supported at $\alpha = 0.05$ at Sveigakot.

9.13.4 Inter-species analysis: Cattle vs. sheep/goat

Comparative inter-species analyses were also conducted, focusing on the identification of any palaeopathological differences in cattle vs. sheep/goat in the Viking Age/Norse results. Despite the variation in assemblage size, there was no significant differences in the frequency of palaeopathological lesions between the two species at $\alpha = 0.05$ ($X^2 = .83$, $p = .3618$, $p > 0.05$, d.f. = 1). In order to further investigate any disparities in the aetiology categories between species in the Viking Age/Norse results, the cattle and sheep/goat data from Hofstaðir and Sveigakot was combined and a series of chi-square tests conducted (Table 9.67).

Table 9.67 X^2 results and *p* value: Viking Age/Norse cattle vs. sheep/goat aetiologies

Viking Age/Norse Aetiologies (cattle vs. sheep/goat)	$X^2_{(1)}$	*P* value	H_0 Accept or reject?
Trauma	.00	.9545	Accept
Arthropathy	113.42	.0000	**Reject**
Congenital	2.02	.1553	Accept
Non-specific bone proliferation	.11	.7383	Accept
Non-specific bone lysis	.04	.8505	Accept
Other (osteochondrosis manifesta)	11.42	.0007	**Reject**

Figure 9.167 clearly illustrates inter-species differences in the proportion of oral pathology, arthropathy and other (predominantly comprising *osteochondrosis manifesta* lesions). Oral pathology could not be compared statistically due to a lack of data for cattle. However, this demonstrates the dominance of this type of pathology in sheep/goat. Significant differences were noted at $\alpha = 0.05$ for both arthropathy and *osteochondrosis manifesta* (OCM) lesions. This provides statistical support that the greater frequencies observed for arthropathy in cattle and osteochondrosis in sheep/goat in Figure 9.167 are irrespective of sample size. Non-specific bone proliferation and bone lysis were both not significant at $\alpha = 0.05$, illustrating that this lesion type did not favour either species and was equally likely to occur in both at these sites.

9.13.5 Iron Age/Romano-British and Viking Age/Norse: Intra-species comparisons

The palaeopathological data for cattle and sheep/goat associated with both the Iron Age/Romano-British and Viking Age/Norse sites was combined and a series of comparative analyses conducted. The aim of these analyses was to highlight any differences in aetiology frequency between these species from two distinct periods in time and two distinct geographical locations. Figure 9.168 presents the combined aetiology data for cattle and sheep/goat.

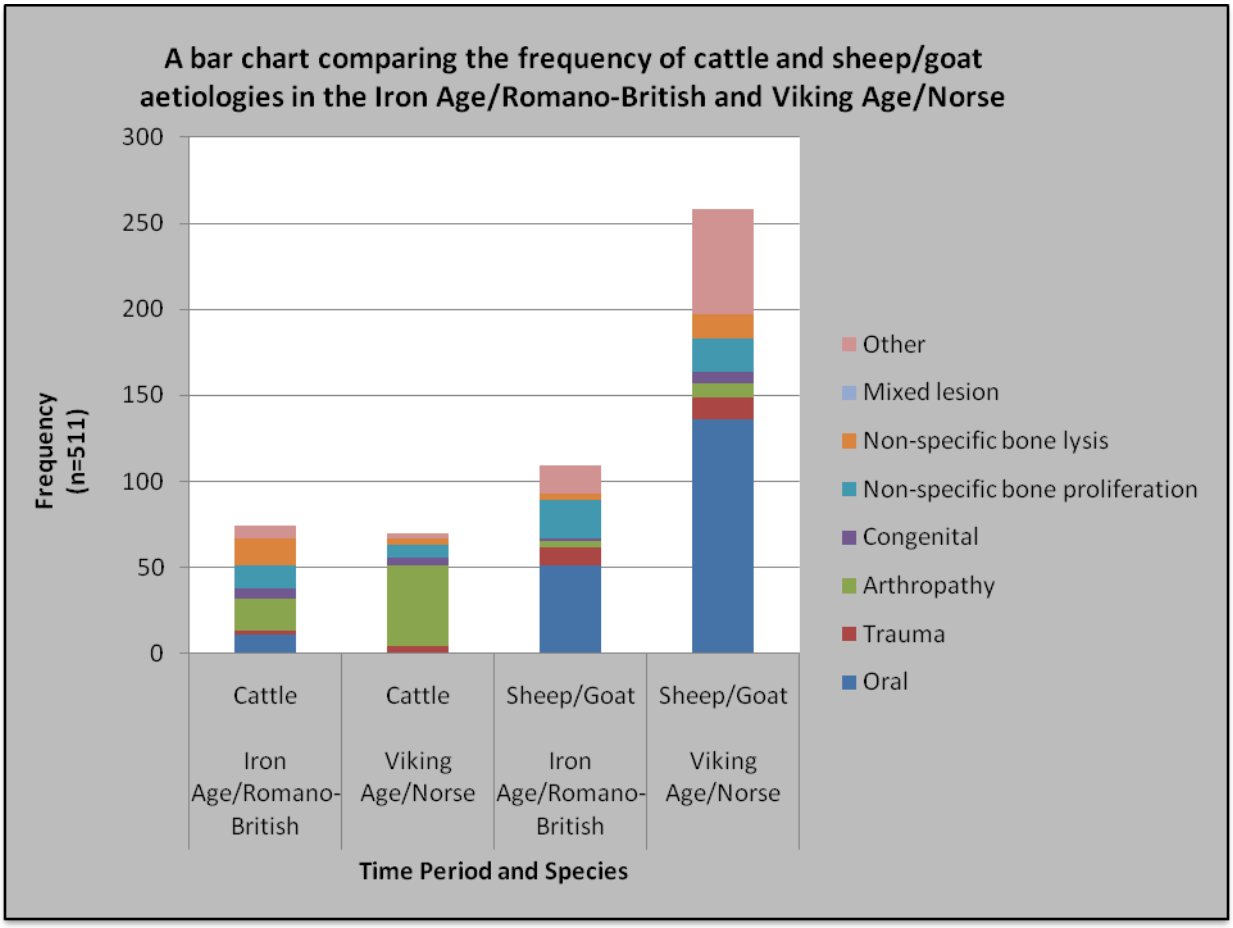

Figure 9.168 A comparison of cattle and sheep/goat aetiologies from the Iron Age/Romano-British and Viking Age/Norse

The data associated with sheep/goat aetiologies in the Iron Age/Romano-British and Viking Age/Norse periods appears proportionately similar in spite of the difference in assemblage size. The aetiologies associated with cattle display different proportions, with a greater emphasis on arthropathy in the Viking Age/Norse. Statistically significant differences were identified in the frequency of palaeopathology in both cattle and sheep/goat when the species were compared between time periods. The results were both significant at $\alpha = 0.05$ (Cattle: $X^2 = 60.01$, $p = .0000$, $p < 0.05$, d.f. = 1; Sheep/goat: $X^2 = 46.13$, $p = .0000$, $p < 0.05$, d.f. = 1). The intra-species comparative results of the aetiology data are presented in tables 9.68-9.69.

Table 9.68 X^2 results and *p* value: Iron Age/Romano-British and Viking Age/Norse, cattle aetiologies

Iron Age/Romano-British vs. Viking Age/Norse Aetiologies (cattle vs. cattle)	$X^2_{(1)}$	***P* value**	**H_0 Accept or reject?**
Trauma	.24	.6250	Accept
Arthropathy	.59	.4418	Accept
Congenital	5.26	.0218	**Reject**
Non-specific bone lysis	32.95	.0000	**Reject**
Non-specific bone proliferation	15.71	.0001	**Reject**
Other (osteochondrosis manifesta)	6.15	.0131	**Reject**

Table 9.69 X^2 results and *p* value: Iron Age/Romano-British and Viking Age/Norse, cattle vs. sheep/goat aetiologies

Iron Age/Romano-British vs. Viking Age/Norse Aetiologies (sheep/goat vs. sheep/goat)	$X^2_{(1)}$	*P value*	H_0 Accept or reject?
Oral pathology	9.27	.0023	**Reject**
Trauma	11.70	.0006	**Reject**
Arthropathy	.54	.4628	Accept
Congenital	.08	.7833	Accept
Non-specific bone proliferation	33.20	.0000	**Reject**
Non-specific bone lysis	.15	.6973	Accept
Other (osteochondrosis manifesta)	.36	.5501	Accept

Significant differences were identified at α = 0.05 in four of the cattle aetiology categories: congenital, non-specific bone proliferation and bone lysis and lesions associated with *osteochondrosis manifesta* (OCM) (Table 9.69). Surprisingly, there was no significant difference associated with arthropathy, suggesting that the proportional differences apparent in Figure 9.168 are likely a product of differing assemblage sizes. Non-specific bone proliferation and bone lysis are more frequent in cattle at the Iron age/Romano-British sites, a pattern especially prominent considering the smaller overall assemblages associated with these sites. Although, the aetiology data for sheep/goat in the two time periods appears proportionally similar in Figure 9.168, significant differences were noted at α = 0.05 in three aetiology categories: oral pathology, trauma and non-specific proliferation. There was no significant difference observed for non-specific bone lysis.

Summary

The results of these comparative statistical analyses highlighted a number of statistically significant differences associated with the frequency of different aetiologies in cattle and sheep/goat. Differences were demonstrated between different sites and time periods. It is important to note that those results that were not statistically significant, especially in relation to non-specific bone proliferation and bone lysis, are equally as interesting as the significant results. This series of comparative results enables the better understanding of different aetiology frequencies in two of the most frequently identified domestic species identified on both Iron Age/Romano-British and Viking Age/Norse sites. In addition, these results provide the basis to develop a better appreciation of the frequency and patterning of non-specific lesions, potentially indicative of infection, in cattle and sheep/goat. These results are further expanded and discussed in Chapter 10.

10. DISCUSSION: THE IDENTIFICATION OF BOVINE TUBERCULOSIS IN ZOOARCHAEOLOGICAL ASSEMBLAGES

'…archaeozoologists unfortunately have not produced very much evidence at all for tuberculosis in wild or domesticated animals from archaeological sites…'

(Roberts & Manchester 2005: 185)

10.1 Introduction

This chapter outlines the problems associated with the study of systemic disease in zoopalaeopathology, before progressing to address the research questions outlined in section 1.5. A brief overview of the context behind each research question is presented, followed by an outline and evaluation of the current research results and how they attempt to answer these questions and form workable solutions to those problems emphasised. The impact of these results and the research in general on the wider research context, particularly in relation to the Iron Age/Romano-British period in southern Britain and the Viking Age/Norse in Iceland is presented to conclude.

10.2 Zoopalaeopathology and systemic disease: The problems

The identification of systemic disease in zooarchaeological assemblages is complicated by two principal factors: more often than not the only material to

survive is bone. As the preponderance of infectious diseases manifest in the soft tissue, the analysis of pathological faunal bones provides only a limited representation of animal disease in the past (unless there are exceptional conditions of preservation) (Siegel 1976: 355). As Siegel stated, '*…what we see in the way of dry bone pathology is only an indication of the bare minimum of disease processes actually at work in antiquity*' (Siegel 1976: 355). In addition, bone is limited in its reaction to insult and injury, making the information available from non-specific, isolated lesions especially difficult to extrapolate to once living animals (Baker 1978: 107). Bovine tuberculosis is by no means the exception to this rule; involvement of the skeleton (in both humans and animals) is late in the pathogenesis of the disease (Mays 2005: 130) and seemingly rare if the published statistics are taken into account (section 3.8). Moreover, if an infected human or animal succumbed to disease prior to skeletal involvement, there would be no macroscopic evidence. Similarly, the early slaughter of infected stock domesticates for meat or ritual purposes would again result in an absence of skeletal evidence (Mays 2005:130). Both scenarios enforce the osteological paradox, that threaten to lead to misconceptions about the health of past herd populations (section 2.5.4). These factors are compounded in zooarchaeology by the frequency of disarticulated, fragmented and co-mingled assemblages and the general lack of information available concerning the lesion distribution of different pathological conditions, lesion morphology and differential diagnosis. These all combine to preclude the better understanding of animal disease and its prevalence in the past.

10.3 The three core components in palaeopathology

The analysis of lesion distribution and the process of differential diagnosis are methods regularly employed in human palaeopathology. In fact, the success and continued development of this sub-discipline is largely a result of the application of these diagnostic tools, in addition to standardised recording protocols and the wide dissemination of data. The inability to observe the distribution and patterning of lesions on a regular and routine basis in zooarchaeology has impeded progress and precluded the regular and consistent identification of specific pathological conditions. This has led to little application beyond the analysis of localised bone pathologies, and as a result, broader questions related to animal health on both regional and temporal scales at the population level have gone unanswered. The limited number of articulated animal skeletons (ABGs) available for analysis has left zooarchaeology with no alternative but to employ an approach generally frowned upon – the analysis of isolated lesions in disarticulated bones. A number of researchers in human palaeopathology have specifically advised against attempts to diagnose and classify isolated osseous lesions. Most notably, Rogers & Waldron stated, '*We repeat here our warning about the very great difficulties in classifying lesions in disarticulated bones or in damaged or incomplete skeletons*' (Rogers & Waldron 1989: 624). However, the reporting of localised pathologies in zooarchaeology has led to advancements in the understanding of certain aetiologies, for example, traction-related pathologies (Bartosiewicz *et al.* 1997). However, whilst the study of localised pathologies has prevailed against circumstance, the low number of pathological articulated animal skeletons has left the study of systemic disease virtually unexplored.

The limited progress of zoopalaeopathology beyond the scope of localised conditions is understandable; a systemic disease cannot be identified from an isolated lesion alone. However, the fact remains that the vast majority of zooarchaeological assemblages are disarticulated and, in order to progress and develop further understanding, there needs to be established reference information for researchers in zooarchaeology, detailing lesion morphology, lesion distribution and differential diagnosis. These three core components underpin palaeopathology and when combined, a continuous cycle is formed that would court continued progress and result in a better overall understanding of animal disease in the past (Figure 10.1).

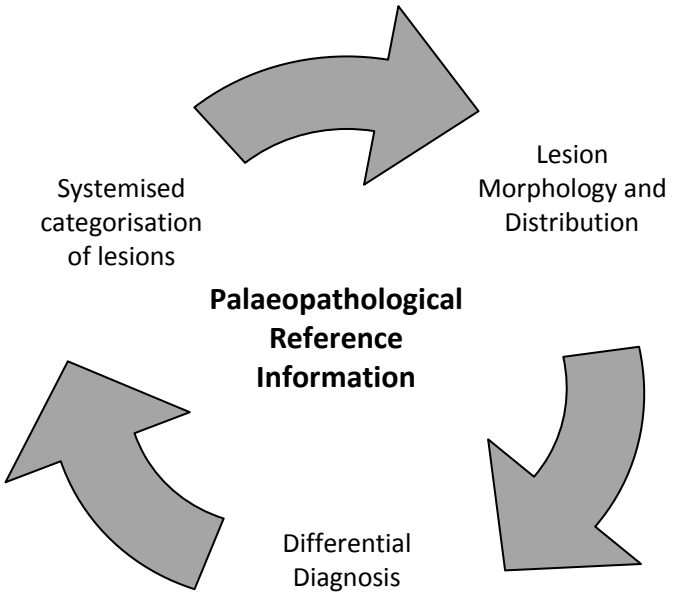

Figure 10.1

Cycle diagram illustrating the continuous progress associated with the provision of palaeopathological reference information in zooarchaeology (Source: Author)

10.4 Zoopalaeopathology: Lesion morphology and lesion specificity

The advent of tuberculin testing and the implementation of control measures especially focused on domestic animals has ensured that the skeleton is rarely

involved in the disease process in modern times. As a direct result, there is a scarcity of pathological skeletal reference specimens for comparative analysis and no real perceived need for them in modern veterinary practice. As Baker highlights, '*In working on the pathological diseases represented in the archaeological record, it is essential to have an extensive reference collection of modern macerated specimens.....Development of such a collection is a slow and laborious task even for the veterinary pathologist, macerated 'dry pathology' being rather looked down upon in these days of electron microscopy...*' (Baker 1978: 107). The only extensive modern collection of which the researcher is aware of is the Baker Collection, compiled by John Baker and analysed as a part of this research. Therefore, in order to investigate skeletal lesion morphology in more detail, reference information was sought from the pre-tuberculin era, when the natural course of disease progressed to involve the skeleton on a more regular basis.

The limited way in which bone may react to disease ensures that determining lesion specificity in association with a particular morphology is problematic. In addition, some pathological changes seemingly pathognomonic may not actually be directly associated with a particular disease. For example, in cases of pulmonary tuberculosis, new bone formation on the visceral surfaces of the ribs, in addition to fragments of calcified pleura, have been commonly identified. In one study, a sample of calcified pleura was positive for MTB complex DNA (see Donoghue *et al.* 1998). However, as Roberts and Buikstra (2005) emphasise, this result does not prove a positive association between lesion type and aetiology. A human or animal skeleton displaying rib lesions and calcified pleural fragments may have been

tuberculous, but a positive aDNA result cannot directly link these non-specific changes to the disease. They may, in all likelihood, have been the result of any number of respiratory complaints, either un-related or secondary to primary pulmonary TB. Therefore, identifying pathognomonic lesions directly associated with this disease in animal bone appeared unfeasible. This was further investigated through the analysis of known cases of bTB in animals, reference to the veterinary literature and by sampling pathological lesions for aDNA analysis.

10.4.1 Bovine tuberculosis: Lesion morphology and lesion specificity

A thorough search of the literature revealed only a small number of a) illustrations of confirmed tuberculous lesions in disarticulated bones and b) animal cases studies with confirmed skeletal tuberculosis. These were outlined in detail in Chapter 3. In both humans and animals, the disease incites a skeletal response that is predominantly lytic in nature. However, a key difference was noted: reactive and reparative new bone proliferation is a prominent feature of the disease in animals, particularly in canids, felids, ruminant species and pigs, whereas in humans there is little new bone proliferation or bone regeneration. The reference illustrations and confirmed case studies appear to support this pattern, with bone proliferation, in some cases being exuberant and forming a definite recurring feature.

Of the disarticulated bones and ABGs recorded, there were only a few identified as possessing lesions similar in morphology to those illustrations published in the early 20th century (section 3.8) and to those case studies reported (section 3.9). These

comprised the following: modern pig ABG, Chester (section 9.4.1); Iron Age medium terrestrial mammal (MTM) rib, Wetwang Slack, East Yorkshire (section 9.5); modern horse rib, the Baker Collection, University of York (section 9.4.5); and Iron Age/Romano-British horse ABG, Wetwang Slack, East Yorkshire (WE 64 AR) (section 9.5.4). The partial pig ABG possessed several space occupying lesions within the vertebral bodies of the lumbar vertebra, accompanied by multiple cloacae, consistent with pyogenic osteomyelitis. In addition, one of these vertebrae also possessed a perforating, resorptive lesion affecting the neural arch and base of the spinous process. These lesions, particularly the latter, are similar in location and destructive morphology to that displayed in the illustration of a confirmed tuberculous focus in a modern pig thoracic vertebral column (Figure 10.2). This pig was sampled for aDNA analysis in the early stages of this research, with preliminary results indicating the presence of MTB complex pathogen DNA; however, the results were not reproducible (section 9.12.1). An MTM rib also displayed a prominent space-occupying lesion affecting the spinous process. This lesion was less destructive and irregular in nature, potentially indicating a more chronic, contained response to a potentially infectious agent. The location of the lesion was reminiscent of the 20th century pig illustration, but there was no vertebral body present to check for additional lesions (Figure 10.2).

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1 2 3

Figure 10.2 Pig lumbar vertebra with resorptive lesion affecting the neural arch and base of the spinous process (1) and medium terrestrial mammal (MTM) rib, Wetwang Slack possessing space-occupying lesion in spinous process (3) (Photo: Author). These are potentially associated with abscess formation similar to that illustrated in the 20th century pig thoracic vertebra image (2, indicated at c on diagram) (Ostertag 1922: 602 cited, in Lignereux & Peters 1999: fig. 6)

The illustrations of tuberculosis affecting three cattle ribs (Figures 3.8.1-3.8.3) all differed markedly in morphology, combining both bone lysis and proliferation. A rib was identified as exhibiting similar lesion morphology to two of the three illustrations (Figure 10.3). The rib belonged to a modern horse from the Baker Collection. It possessed a large space-occupying lesion in the body of the rib, accompanied by a cloaca, swelling and a pathological fracture – consistent with pyogenic osteomyelitis (section 9.4.5). Although there was little exuberant new bone proliferation as displayed in the modern images, this may not have survived maceration, especially in light of the pathological fracture. However, the location of the lesion and its general morphology was similar to those illustrated. This rib was sampled for aDNA analysis with preliminary results identifying *M. bovis*. This

promising result is currently in the process of being replicated so cannot be taken as definitive at this stage.

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a b c

Figure 10.3 Tuberculosis affecting the body of the rib in two specimens. The first (a) displays proliferative bone formation and pronounced swelling with an area of bone lysis at the centre (Kitt 1905: Fig 198). The second (c) displays exuberant new bone proliferation described as 'spina ventosa' (Cohrs 1967: 639). These are compared with a cattle rib from the Baker Collection (b), possessing a large space-occupying lesion and a smooth, remodelled, lesion interior (Photo: Author).

Finally, a horse ABG recorded at Wetwang Slack possessed mixed lesions comprising both bone proliferation and bone lysis in a number of thoracic spinous processes (section 9.5.4). This was also associated with osteomyelitis. These lesions were very similar in morphology and location to those published in the case of a modern horse diagnosed with *M. bovis* (section 3.9.3) (Figure 10.4). The horse from Wetwang Slack was sampled for aDNA but initial attempts to amplify both MTB complex and *brucella* pathogen DNA were unsuccessful.

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a b

Figure 10.4 Horse ABG, Wetwang Slack (WE 64 AR): Osteomyelitis of a thoracic spinous process (a). This is similar to a lesion identified in a horse diagnosed with *M. bovis* (b) (Kelly *et al.* 1972: fig 4). Both display osteolytic lesions at the dorsal tip and swelling of the spinous process.

Although limited in number, the illustrations from the early 20th century veterinary text-books constitute a valuable visual aid, particularly for cattle and pig. While there is some definite similarity between the illustrations and the pathological bones presented above, they cannot be assumed to be tuberculous based upon lesion morphology alone – though careful consideration of morphology along with location does help to narrow the potential list of differential diagnoses.

Overall, the information available from the case studies, images, illustrations, lesion descriptions and preliminary aDNA results provide a valuable opportunity to observe the different manifestations of skeletal lesions seemingly associated with MTB complex disease, specifically bTB. This information enables the observation of potential species-specific differences in lesion morphology and lesion location. In addition, different types of lesion that may affect the same species or even the same bone may also be observed, for example, the three very different reference illustrations for rib tuberculosis in cattle (section 3.8).

10.4.2 Lesion specificity and the application of aDNA analysis

A number of other bones with osseous lesions identified during this research were also sampled for aDNA analysis and the preliminary results are presented in section 9.12. The results were mixed, but the most recent series of tests focusing on six disarticulated bones (JW1-JW6) (section 9.12.3) employed a more refined method, targeting smaller amplicons (79 bp and 70 bp). Where possible, the pathological lesions were sampled directly. The preliminary results are very promising, and if the results are successfully replicated, they could add valuable information to the reference illustrations and case studies of lesions associated with known tuberculous animals, further broadening our understanding of this disease and the potential skeletal characteristics associated with it. There still remains the difficulty of determining absolute lesion specificity using aDNA, even where the lesions are directly sampled. However, the value of this research lies within the identification of potential candidates for further analysis.

Research conducted by Baron *et al.* (1996) and Faerman *et al.* (1997) reported the successful extraction and amplification of MTB complex DNA from bones displaying macroscopic lesions, bones that were lesion free and even teeth. This supports the pathogenesis of the disease and its haematogenous dissemination throughout the infected host (Faerman *et al.* 1997: 211). This also suggests a sample from any bone could theoretically confirm the presence of disease in infected humans or animals. This also presents the opportunity for miss-association of unrelated osseous lesions to MTB complex disease. This contrasts with a more recent statement made concerning the negative results associated with a human bone displaying osteological evidence for MTB complex disease, '*Although bone 73 showed clear osteological indications of tuberculosis, the DNA extract was prepared from a different part of the skeleton and hence the negative result with this sample is not surprising.*' (Bouwman and Brown 2005: 6). It is logical to assume that a lesion directly associated with infection would contain the highest concentration of pathogen DNA (as demonstrated by the modern horse case study – see section 3.9.3, Kelly *et al.* 1972) and that levels would invariably differ in other regions of the skeleton, potentially associated with blood supply. However, it has been demonstrated in the studies above that pathogen DNA can be amplified from unaffected bones, therefore, the possibility must be ventured that the osteological evidence for TB reported by Bouwman & Brown (2005) in the particular bone tested was not specific to MTB complex disease. Although, it is also important to note that negative results do not always indicate a lack of infection, with the possibility of false negatives being generated as a result of poor TB biomarker preservation and/or PCR inhibition (see Donoghue *et al.* 2009).

Clearly, there exists a complex interplay of factors associated with the preservation and successful extraction, amplification and replication of pathogen DNA in archaeological bones. For example, Barnes and Thomas (2006) failed to identify evidence for pathogen DNA using sensitive PCR methods in 59 human skeletons known to have been infected with either *Mycobacterium tuberculosis* or *Treponema pallidum.* The skeletons dated to the 18th and 20th centuries and formed part of a museum osteological collection. These results are surprising considering the age of the specimens. In addition, the strength and durability of the acid-fast *mycobacterium* cell wall is often cited as the reason for the success of *mycobacterial* aDNA research, particularly in human remains (Spigelman & Donoghue 1999:355; Nerlich & Zink 2008:114). Whereas, MTB complex DNA was successfully extracted, amplified and replicated from a 17,000 year old Bison bone (section 3.14.2) (Rothschild *et al.* 2001). The inability to amplify pathogen DNA associated with venereal syphilis (*T. pallidum*) has been consistently demonstrated by Bouwman and Brown (2005) and also in the study by Barnes and Thomas (2006). These two cases illustrate the rare publication of negative results (Bouwman & Brown 2005: 10). However, these are just as informative as positive results in gaining a better understanding of the complicated relationship between host and pathogen and the way in which evidence of this is stored within the skeleton.

Roberts & Ingram (2008) and Wilbur *et al.* (2009) highlight a number of concerns about the application of aDNA analysis to palaeopathology, the latter specifically focusing on the identification of MTB complex disease in archaeological human remains. Concerns associated with consistency and reliability of methods, the

potential for contamination and the validity of results were outlined. These comments instigated much debate and appear largely unjustified, resulting in detailed responses from several authors in the biomolecular community (see Taylor *et al.* 2009 and Donoghue *et al.* 2009). However, the emphasis placed upon maintaining caution when attributing osseous lesions to specific diseases by Wilbur *et al.* (2009:1991) is valid: '*The critical issue when considering skeletal evidence for TB is to be aware that there are no pathognomonic lesions – those that can be considered specific to TB – and rather we are left with lesions that are 'consistent with' a diagnosis of TB but also consistent with other conditions.'*

In zooarchaeology, there are additional compounding factors that may hinder the retrieval of pathogen DNA, including, the more complicated taphonomic pathways associated with faunal remains, as outlined in section 2.5.3 and illustrated in Figure 2.1. If the preliminary aDNA results associated with this research (JW1-6) are successfully replicated, the more refined method devised by Dr. G.M. Taylor, targeting smaller amplicons represents an exciting and important development in the analysis of animal disease. In Table 9.59, it is clearly demonstrated that positive results are only identified in association with the smaller amplicons (79bp and 70 bp). This infers that degradation of pathogen DNA is more severe in zooarchaeological remains. It cannot escape attention that the earlier results associated with the modern case studies were negative; larger amplicons were utilised in these early experiments (135 bp and 113bp) prior to the refinement of the method. These initial negative results may be valid, but in light of the recent preliminary findings and the fact that some of the lesions associated with these

modern case studies, for example, the pig from Chester, were clearly associated with systemic infection would definitely justify their re-analysis using the more refined method to definitely rule out MTB complex disease as well as perhaps, brucellosis.

Regarding absolute lesion specificity and the application of aDNA, this research indicates that only when replicated positive results associated with a particular lesion type are consistently reported in a statistically viable sample can lesion specificity begin to be demonstrated. Until then, it is would appear reasonable to assert that osseous lesions in association with a positive TB result can be considered as '*consistent with' a diagnosis of TB...'* (Wilbur *et al.* 2009: 1991). Although there is one pattern emerging from studying the illustrations, the modern horse case-study and the preliminary aDNA results: the association between osteomyelitis and MTB complex disease. Tuberculous osteomyelitis is a documented feature of the skeletal manifestation of this disease (section 4.2.3) and this reference information appears to support this.

This brief discussion serves to illustrate the complexities associated with aDNA analysis and the necessary caution required in determining lesion specificity. However, where pathogen DNA survives, and it is supported by other palaeochemical analyses targeting lipid biomarkers, such as mycolic acids (see Gernaey *et al.* 2001 and Minnikin *et al.* 2010), there is no reason why progression towards a more informed appreciation of the osteological appearance of TB cannot be achieved if large enough samples are targeted. This would lead to a much

needed, better understanding of palaeoepidemiology in past animal populations (section 2.7).

10.5 Zoopalaeopathology: Lesion distribution

In zoopalaeopathology, there is currently no comparative dataset of lesion distribution data. This is why those published studies describing palaeopathological articulated animals by Bendrey (2004), Bendrey *et al.* (2008), Bathurst & Barta (2004) are so crucial. Even in the event where no definitive diagnosis is possible, as in the case of Bendrey *et al.* (2008), it is still important to report and disseminate the information. As Bendrey *et al.* (2008: 1588) stated '*it is important to undertake and publish palaeopathological and aDNA work providing detailed descriptions, in order to help establish osteological criteria for the identification of certain diseases....and promote awareness of the variety of manifestation of bone disease likely to be encountered by other researchers.*'

The limited numbers of pathological articulated animal skeletons available for analysis does not make the task in anyway easy. Morris evaluated both published and unpublished reports and compiled a data-set totalling 2062 ABGs from southern Britain (Morris 2008a). These included cattle, sheep/goat, pig, horse, dog, cat, wild mammals, domestic and wild bird, fish and snake (Morris 2008a: 284). Excluding the fish and snake, only 26% of the ABGs recorded were complete. Table 10.1 presents data for the three main domesticates (cattle, sheep/goat and pig) and horse. These results confirm that the recovery of complete animal skeletons is by no means routine. In addition, the identification of pathological examples is also

infrequent. Just 2% (n=48) were identified as possessing pathological lesions (Morris 2008a: 303). No pathological pig skeletons were identified, with both cattle and sheep/goat representing only 1% of the total.

Table 10.1 Number of complete and pathological cattle, sheep/goat, pig and horse ABG's identified (data adapted from Morris 2008a: Table 69)

Species	No. Identified	% Complete	No. Pathological	% Pathological
Cattle	303	16%	3	1%
Sheep/Goat	437	20%	4	1%
Pig	181	35%	-	-
Horse	155	8%	16	10%

The majority of pathological lesions were associated with horse (10%) and dog (4%) and predominantly comprised arthropathies, followed by trauma. No evidence for systemic disease was identified, with only two cases of non-specific infection noted affecting dog (Morris 2008a 304-5). The combined lack of complete animal skeletons (particularly of the three main domesticates) with the lack of pathological lesions makes it incredibly difficult to employ skeletal lesion patterning as an aid to differential diagnosis on a regular basis. In addition, this also precludes the opportunity to formulate lesion distribution criteria for different pathological conditions. Therefore, it is necessary to compile this information from the veterinary literature. The risk involved is assuming that disease follows the same pattern in present day animals as it did in the more distant past. However, at present, there is little alternative. The presence of established criteria would inform

the recording of pathological articulated remains, which would in turn lead to the amendment of the original criteria. If zoopalaeopathology is to successfully explore systemic disease, then better reporting of lesions is fundamental.

10.5.1 Bovine tuberculosis: Lesion distribution

Two illustrations presenting the lesion distribution and predilection sites associated with bTB in cattle and pigs were created (Figure 8.2). A similar illustration displaying the patterning of lesions associated with MTB complex in humans was also created, highlighting those regions of the skeleton that may, in some cases, be involved in gastro-intestinal infection (Figure 8.3). Cattle and pig were specifically selected because they are reported to display skeletal lesions on a more regular basis than horse, sheep and goat. The latter species, goats, are reportedly more resistant to this type of infection (Chapter 3). These illustrations provide a visual representation of bTB, providing an indication of the key predilection sites.

When comparing the illustrations, it is perhaps unremarkable that the disease largely follows the same pattern in cattle and pig as it does in humans. The axial and appendicular skeleton form the primary targets, with the cancellous bone a principal target for the bacilli. However, the literature and the reference illustrations outlined in section 3.8 do highlight some key species-specific differences in favoured predilection sites – particularly obvious in pigs. By comparison to cattle, the pelvis is commonly affected in pigs, although there has been debate as to which part is most frequently involved, with some reporting the ischium and others highlighting the ilium (Cohrs 1967: 855). In addition, the spinous

processes also appear to be involved in pig, as evidenced in the modern reference illustration (see Figure 3.13). The vertebral bodies of the axial skeleton along with the weight-bearing joints of the appendicular skeleton are primary targets in cattle, pigs and humans. The thoracic vertebral bodies are the main predilection sites in cattle and pig, whereas it is the lower thoracic and lumbar vertebrae in humans. In all three, the knee joint forms a prime target, along with the hip joint in humans and pig. The bones of the hands and feet are only affected on a regular basis in humans, particularly the young (*tuberculous dactylitis*) (see Ortner 2003).

A number of modern and Iron Age/Romano-British ABGs were analysed during this research allowing for the observation of lesion distribution. The overwhelming majority of the lesions identified were observed in the axial and appendicular skeleton – the primary locations for systemic, bacterial diseases, such as MTB complex and brucellosis (see Chapter 4). Apart from the pig ABGs at Wetwang Slack, there was a significant difference at $\alpha=0.05$ associated with lesion distribution in the cattle at Wetwang Slack and the cattle and pigs at Danebury Hillfort. This illustrates that the patterning of lesions in the axial and appendicular skeletons are unlikely to be due to chance and reflect representative lesion distributions. Focusing specifically on cattle and pig, the only ABG that possessed lesions that compared favourably to the reference information in relation to both lesion morphology and lesion distribution was the modern pig from Chester (section 9.4.1). A number of lytic lesions were observed in the lumbar vertebra. Mixed proliferative and lytic lesions were also identified in the pelvis and the scapula. These skeletal elements

are predilection sites in MTB complex disease, brucellosis and non-specific pyogenic osteomyelitis. The cattle ABGs analysed at Wetwang Slack and Danebury Hillfort possessed a mixture of both proliferative and lytic lesions. Although these lesions are located in the correct skeletal regions for MTB complex disease, the morphology of the lesions were not as destructive as those depicted in the modern reference illustrations. The two cattle ABGs described in detail (WE 8 AQ and WE 81 BG) both possessed non-specific pleural rib lesions, though, suggesting the presence an active respiratory infection at death. However, the aDNA results for these ABGs targeting both MTB complex and *brucella* pathogen DNA were negative. The amplification of mitochondrial DNA (mtDNA) was successful for WE 8 AQ, but unsuccessful for WE 81 BG. This suggests that DNA degradation was unlikely to be the reason for the lack of pathogen DNA in WE 8 AQ and the animal was not suffering from either of the two diseases at death. However, for WE 81 BG where no mtDNA was amplified, aDNA degradation can be ventured as a possibility and TB and brucellosis cannot be categorically ruled out. A juvenile cattle skeleton from Danebury Hillfort (DA P909) possessed a number of lytic lesions in the axial skeleton in keeping with the predilection sites associated with bTB. A number of those affecting the vertebral bodies were highly destructive. This ABG was not sampled for aDNA analysis, but the differential diagnoses included systemic disease. An illustration for the lesion distribution of bTB in horses was not compiled as the two most frequently affected species (cattle and pig) were focused upon, however, a series of interesting lesions were identified in the horses from Wetwang Slack, with one (WE 64 AR) possessing lytic lesions in the spinous processes strongly resembling the lesions identified by Kelly *et al.* (1972) in the modern confirmed case of bTB in a horse (section 3.9.3).

However, this ABG was negative for both MTB complex DNA and *brucella* pathogen DNA (section 9.12.2). The presence of mtDNA was also unconfirmed. Therefore, it is unclear as to whether this horse was indeed suffering from either MTB complex disease or brucellosis, or if the aDNA was too degraded for amplification or whether the horse was free of these diseases altogether.

The majority of lesions from both the ABGs and the disarticulated remains were located within the axial and appendicular skeleton, with the former more frequently affected. Therefore, the reference to known lesion distribution illustrations may appear largely ineffectual, especially when focusing upon systemic diseases that primarily target the axial and appendicular regions of the skeleton. However, there are two key reasons for the widespread application of these illustrations in zooarchaeology. First and foremost, in the presence of pathological ABGs, not only can lesion distribution be compared to reference illustrations, but also and most crucially, predilection sites. To know that the pelvis in pigs is a key area for tuberculous lesions would add weight to the inclusion of this as a differential diagnosis in the event where a pig ABG is identified with systemic lesions, including involvement of the pelvis. Secondly, these reference illustrations can also help to inform the differential diagnosis process in disarticulated, non-specific lesions. Although there would be a high number of possible aetiologies for any isolated non-specific lesion, reference to information about the lesion morphologies and distributions for different diseases and species-specific predilection sites would aid in the better understanding and general classification of these lesions.

10.6 Zoopalaeopathology: Differential diagnosis

In human palaeopathology, although disarticulated and fragmented human bone is regularly identified at archaeological sites (Knüsel & Outram 2004: 85), it is not normally analysed on a regular basis. Assemblages have been recovered and studied, including those within ossuaries (Pfeiffer 1984), cremated material (McKinley 2000) and those identified from cave sites (Nagar *et al.* 1999) and more recently a method for the recording of fragmented and co-mingled human and animal bones was devised based upon a method already established in zooarchaeology (see Knüsel & Outram 2004). The difference concerning the study of pathological disarticulated remains in human palaeopathology and zoopalaeopathology is knowledge and data dissemination. In human palaeopathology, reference information exists borne from the regular analysis and publication of skeletal reports, textbooks and published articles containing articulated pathological individuals. Therefore, established datasets are available from which to compare, contrast and differentially diagnose the pathology present in disarticulated human remains. At present, zooarchaeology has no such established framework or dataset in place from which to draw guidance – this is a situation that needs to change if the routine recording of infectious and non-localised palaeopathological lesions, their description or their differential diagnosis will ever be considered a standard part of zooarchaeological practice. Even when articulated examples are examined – with no definitive confirmation of the causative agent and no modern specimens or differential diagnostic criteria from which to compare, the pathological condition exhibited is in danger of becoming another 'interesting specimen', as highlighted by Thomas & Mainland (2005: 2). This

is where description, as emphasised by Bendrey *et al.* (2008), and publication of findings is paramount and upon which this research aims to build.

10.7 Identifying infection in disarticulated and fragmented bones

The differential diagnosis of bTB in both animals and humans was presented in Chapter 4, along with a series of reference tables highlighting key predilection sites, and lesion morphologies. This information aimed to identify disease in articulated remains. However, by providing this information, a better appreciation of the different types of disease that could potentially mimic lesion morphologies and distribution patterns in disarticulated bones was also highlighted, allowing for the more informed compilation of aetiologies and the possible identification of infection. Without the ability to observe lesion distribution, it is especially difficult to identify definitive evidence for systemic disease. Consequently, there is untapped information potentially available that researchers do not currently possess the means to explore. This research sought to tackle this by isolating those lesions that may potentially indicate infection in disarticulated bones. A method of lesion type classification following Ortner (2003) was employed; these lesion types were then categorised by general aetiology. Those lesions identified as either abnormal bone lysis or bone proliferation and not associated with any other obvious aetiology were categorised as possible evidence for infection. The morphology and location of these lesions were further explored and analysed using statistical analyses. The aim of this was to investigate the level of information retrievable from non-specific lesions and the potential for identifying evidence of systemic infection, possibly even bTB. This research highlights the need for a structured and standardised

approach to the recording and classification of palaeopathological lesions in zooarchaeology, specifically lesions associated with infection. It cannot be assumed that biomolecular methods will provide the answers sought concerning systemic disease in past animal populations. These methods are expensive, time consuming and subject to a number of factors affecting the outcome and validity of results. Ancient DNA (aDNA) works best when employed as a complementary tool, alongside a structured recording framework designed to highlight potentially infective lesions for further study and analysis. The latter is essential, as without a framework for targeting these lesions, consistency in lesion classification will remain with no identifiable patterns associated with lesion types and locations. There would also be no way of comparing the frequency of lesion types between species, sites and time-periods – an essential step forward if researchers are to begin to appreciate the prevalence (albeit crude) of infection, and specifically, systemic diseases in the past.

Evidence for potential non-specific infection was identified at all sites in varying frequencies (Table 10.2). At Barton Field and Wetwang Slack (Iron Age phase), non-specific bone proliferation was the most common pathology type observed. Cattle and sheep/goat demonstrated the highest number of incidences, which is likely a reflection of their dominance in the assemblages as a whole.

Table 10.2 Frequency of non-specific infection

Sites/Assemblages	INFECTION?	
	Non-specific bone proliferation (%)	Non-specific bone lysis (%)
Wetwang (Iron Age)	32	14
Wetwang (Iron Age/Romano-British)	19	6
Barton Field	24	16
Danebury Hillfort	11	3
Westness	8	25
Hofstaðir	12	5
Sveigakot	4	8
Hrisheimer	2	8

Periostosis comprised the greater majority of non-specific bone proliferation lesions identified at all sites, with a few isolated cases of endostosis. These lesions were most often identified in the appendicular skeleton, supported statistically where the data allowed (Table 10.3). Periosteal new bone formation can occur in response to a number of different pathological conditions, including specific and non-specific infections and trauma. Weston demonstrated that periosteal lesions were not specific to any disease type, with differences in lesion morphology associated more with disease duration (Weston 2004: 309). However, where periosteal new bone formation does occur in humans suffering from TB, it is most often associated with tuberculous osteomyelitis, tuberculous arthritis and tuberculous dactylitis (Weston 2004: 61). Similarly, in animals, tuberculous periostitis is reportedly associated with

extension from disease in the joint or bone marrow (Cohrs 1967: 858). The majority of periosteal lesions were located in the appendicular region, with a smaller number also located in the axial region (specifically the ribs). The lesion distribution data, supported at three sites by statistically significant results, strongly suggest a preference for periosteal lesions in the appendicular region. The majority of these identifications consisted of isolated patches of new bone, not obviously associated with any other pathological alteration. Therefore, a proportion of those observed may, in fact, be associated with aetiologies other than infection, for example, localised trauma, especially when identified in isolated patches on the diaphyses.

There was more variety with the non-specific bone lysis lesions. These comprised pitting/porosity, porous lytic lesions, resorptive lytic lesions, space-occupying lesions, cystic lesions and enlarged foramina. There was not enough data available to statistically test the lesion distribution associated with this lesion type at all sites, however, the axial region (specifically the vertebral column) was demonstrated as favoured at Barton Field (Table 10.3). At the other sites, bone lysis also appeared to favour the axial region, although this could not be demonstrated statistically as reflecting a representative pattern. Although lytic lesions were identified in the appendicular skeleton in a number of cases, the preponderance of lesions in the axial region suggests that it, and specifically the vertebrae are predilection sites for potentially infective lytic lesions.

A horse rib from Barton Field with a periosteal lesion located on the visceral surface was sampled for aDNA analysis (section 9.12.3). This lesion is a non-specific indicator of respiratory infection of which MTB complex disease would be included as a possible differential diagnosis. The preliminary results identify *M. bovis,* although the results are currently in the process of being replicated at a second centre. If confirmed, this would add weight to the inclusion of MTB complex disease, and specifically *M. bovis* as a differential diagnosis for non-specific rib lesions.

The specific lesions identified as associated with non-specific bone lysis could represent a number of aetiologies, but obvious associations with arthropathy and trauma were ruled out. The two lesion types observed on a regular basis in the vertebrae include porous, lytic lesions within the vertebral foramen exposing the trabecular bone and enlarged foramina within the vertebral foramen and also on the ventral aspects of the vertebral bodies. The varying aetiologies associated with these lesion types were outlined in the results chapter. They were both consistent in morphology across species and sites, representing two distinct bone responses that require further analysis to determine causality. The porous, lytic lesions represent a loss of bone density and hypervascularity in the vertebrae. This could be a feature of infection, perhaps the early stages of inflammation due to infection, invoking a generalised bone loss response. Another possibility is nutritional deficiency/stress. The lesions were most often identified in sheep/goat and cattle so could potentially be associated with animals under stress, possibly a sign of dairy animals or animals with a deficient diet – a possible indicator of over-wintering.

Enlarged foramina were consistently identified in cattle, sheep/goat and horse, but the degree of enlargement varied. This may suggest that the enlargement is a progressive feature associated with a particular aetiology. Those that were subject to radiography revealed sclerotic margins with the affected foramina resembling channels. This morphology would appear to indicate that the enlargement served a function other than that involved with the normal passage of blood vessels through the bone. Some of these may represent convenient outlets for purulent exudate within the vertebral foramen, basically substitute cloacae, especially when they appear in association with space-occupying lesions. Although the lack of regularly observed reactive bone on the ventral surface of the vertebral bodies would seemingly rule this option out, the sclerosis does suggest a long-standing, chronic alteration. The sclerosis may be associated with normal blood-flow and larger than normal blood vessels (Roha 2005: 149-50). Although these features suggest increased blood flow, which in turn may suggest the presence of infection (passive hyperaemia). Baker and Brothwell (1980: 35) propose a congenital aetiology for these foraminal variations, which is another valid hypothesis. The lack of conformity in size would suggest that the malformation was random and irregular – although this does not explain the sclerotic margins. This lesion type was also highlighted by Roha (2005) in her research on TB in archaeological faunal remains.

However, in a thorough differential diagnosis, Roha discounts this possibility as there was no other evidence for the presence of tubercles within the vertebrae (Roha 2005: 155).Therefore, the aetiology of this specific lesion type requires further attention. If associated with infection, it is unlikely to represent an indicator

for one specific infection such as TB, but rather an indicator for a change in blood flow that may highlight the presence of infection. With further investigation, this lesion type could potentially be used as a target for further biomolecular analyses.

Table 10.3 A summary of the statistical test results targeting NSBP and NSBL between species and sites

Disarticulated Assemblages	Significant Difference at α = 0.05?				NSBP (favoured skeletal region)	NSBL (favoured skeletal region)
	Cattle vs. Sheep/Goat		NSBP Distribution	NSBL Distribution		
	NSBP	NSBL				
Wetwang (Iron Age)	×	✓	✓	×	Appendicular	-
Wetwang (Iron Age/Romano-British)	×	×	-	-	-	-
Barton Field	×	✓	✓	✓	Appendicular	Axial
Hofstaðir	×	×	✓	×	Appendicular	-
Sveigakot	×	×	-	×	-	-

NSBP – Non-specific bone proliferation

NSBL – Non-specific bone lysis

The frequency of non-specific bone proliferation and non-specific bone lysis were also compared by species and time period (Table 10.4).

Table 10.4 A summary of the statistical test results targeting NSBP and NSBL between species and time periods

Individual sites and time periods (disarticulated assemblages)	Significant Difference at α = 0.05?					
	Cattle vs. Cattle		Sheep/Goat vs. Sheep/Goat		Cattle vs. Sheep/Goat	
	NSBP	NSBL	NSBP	NSBL	NSBP	NSBL
Wetwang (All phases) vs. Barton Field	×	×	×	×	×	✓
Hofstaðir vs. Sveigakot	×	×	✓	×	×	×
Iron Age/Romano-British vs. Viking Age/Norse	✓	✓	✓	×	-	-

NSBP – Non-specific bone proliferation

NSBL – Non-specific bone lysis

The results for the inter and intra-species analyses in the two time periods indicates, in the majority of cases, a lack of significant difference in the frequency of either lesion type. This suggests that both species possessed the same chance of developing these lesions. The exceptions were non-specific bone lysis between cattle and sheep/goat at Wetwang Slack vs. Barton Field and non-specific bone proliferation between sheep/goat at Hofstaðir vs. Sveigakot. The significant differences verify the patterns identified. Cattle at Wetwang Slack possessed more non-specific bone lysis than sheep/goat at Barton Field and sheep/goat at Hofstaðir

possessed more non-specific bone proliferation than sheep/goat at Sveigakot. The latter largely associated with a high frequency of new bone formation associated with oral pathology at Hofstaðir.

When the Iron Age/Romano-British data is compared with the Viking Age/Norse data, significant differences are confirmed in all but the frequency of non-specific bone lysis between sheep/goat in each time period. This pattern suggests that sheep/goat were consistent in their reduced frequency of non-specific bone lysis by comparison to cattle both within the same site, regionally, within the same time period and also on a temporal scale.

A number of the disarticulated bones highlighted as potentially displaying infection were also supported by lesion morphologies that broadly resembled the 20th century reference illustrations. These included a MTM spinous process, already highlighted in section 10.4.1. In addition, an MTM rib from Hrisheimer (section 9.11) displayed a swelling in the neck region, coupled with microporosity and two cloacae - an example of osteomyelitis of the rib, but not a by-product of any obvious trauma. This bone did not display any exuberant bone formation or obvious lytic cavities as depicted in the reference images, but the swelling of the bone and the identification of cloacae indicated the presence of infection. This bone was sampled for aDNA and the amplification of spacer 23 on the DR region suggests the potential identification of *M. bovis* in the preliminary aDNA results. However, this is currently undergoing replication and cannot yet be confirmed. A large terrestrial mammal

(LTM) lumbar vertebral body from Danebury Hillfort displayed destruction of the vertebral plate, with sclerosis and microporosity. The bone lysis did not extend far into the vertebral body, but there was complete loss of the majority of the articular surface. This infective process either spread directly through the intervertebral disc from a neighbouring vertebra or the infection infiltrated the disc space from a soft-tissue focus. This vertebra was also sampled for aDNA and the preliminary results identified a near complete fingerprint of *M. bovis* upon spoligotyping (section 9.12.3). These results are currently being replicated.

The classification of lesions potentially indicative of infection in this research highlighted the potential for information to be extracted from disarticulated assemblages and pathological lesions deemed non-specific because of their lack of association with other lesions in the same skeleton. By considering lesion location and lesion morphology and comparing these with reference information for known diseases and lesion predilection sites, such as that produced here for bTB, at the very least a more informed list of differential diagnoses can be formulated. This more structured approach also highlighted specific lesion types that may indicate infection and, as such, may prove to be general target indicators for the presence of infection in domestic animal species, for example, enlarged foramina. This is a factor that would inform further research and the selection of bones for aDNA analysis. This approach demonstrates the potential for zoopalaeopathology to begin to address wider questions regarding animal health in the past and move beyond the analysis of localised pathologies and 'interesting specimens'.

10.8 The wider research implications

If the preliminary aDNA results are replicated, this demonstrates the presence of bTB in two modern bones and also two specific time periods in the past, when humans and animals lived in close proximity (Chapter 5): the Iron Age/Romano-British period in southern Britain and the Viking Age/Norse in Iceland. The wider research implications of these results and the research in general are discussed below.

10.8.1 Modern bones: The Baker Collection

The two modern bones from the Baker Collection comprised a horse rib and pig scapula (section 9.45). If these results are confirmed they illustrate the continued presence of *M. bovis* in modern domestic animals, despite stringent control measures and heightened awareness in the present day. The lesions associated with both bones are striking, especially for modern animals whose close management would presumably prevent such disease progression. The pig scapula was unfused and belonged to an animal less than a year of age at death. This illustrates that involvement of the skeleton was swift, highly destructive and not the end product of a long-lasting chronic infection. If the lesions observed are the result of *M. bovis,* this may suggest that skeletal involvement was either early in the pathogenesis of the disease (pig scapula), or alternatively, the overt symptoms of disease remained subdued until the point where the skeleton was involved and the animal displayed either acute lameness or obvious discomfort. It has been documented that apparently 'healthy' animals upon slaughter have been found to be riddled with

disease (Chapter 3). The legacy of the 'osteological paradox' in a modern setting – just because they look healthy does not mean that they are. These lesions certainly appear extreme, but in all likelihood, skeletal involvement of this nature could be a regular occurrence in modern domestic animals. With the emphasis placed firmly on the soft-tissue diagnosis of disease, particularly in domestic livestock, the skeleton is largely ignored – a reason for the notable lack of reference specimens. Further analysis of wild animals confirmed as being infected with *M. bovis* would help to further investigate the 'timetable' associated with skeletal involvement.

10.8.2 The archaeological bones

The three potentially positive bones dating to the Iron Age and Iron Age/Romano-British period were: a large terrestrial mammal (LTM) (probably cattle) lumbar vertebra and a horse cranium and contiguous atlas vertebra (section 9.7.1) from Danebury Hillfort and a horse rib (section 9.6.2) from Barton Field, Tarrant Hinton. The single bone dating to the Viking Age/Norse period was a medium terrestrial mammal (MTM) (probably sheep/goat) rib (section 9.11.1) from Hrisheimer, Iceland. If associated these lesions provide informative morphological and distribution data to supplement the current reference information. In addition, the understanding of animal health in southern Britain during the Iron Age/Romano-British period and Iceland in the Viking Age/Norse would be improved, allowing for more in-depth analyses of animal husbandry, animal management and the impact of animal disease in past communities, as well as, working towards a better appreciation of palaeoepidemiology.

10.8.3 Iron Age/Romano British: Research implications

The bones dating to the Iron Age/Romano-British period, if successfully replicated, illustrate the presence of *M. bovis* in the animal populations of two very different settlement types: Danebury hillfort, a large, imposing and complex settlement site possessing a higher density human population and evidence for the burial of multiple ABGs (section 6.6.3) and Barton Field: a small, agrarian settlement site also associated with the earliest identified case of *M. tuberculosis* (to date) in the corresponding human population (section 6.6.2). This would suggest that the disease was not isolated but potentially even endemic in some regions or settlements with a high enough density of animal herds to maintain infection. If this is found to be the case and more identifications are made, it would be interesting to analyse a wider array of human remains both with osteological lesions consistent with TB and without them, in an attempt to formally identify *M. bovis* and gain an understanding of its frequency. Positive results would establish the zoonotic connection between humans and animals, as demonstrated recently in Siberia (section 3.12.6). As demonstrated in Chapter 5, there were numerous avenues of infection facilitating the zoonotic transmission of disease in the Iron Age, supported by the evidence for dairying and breast-feeding (section 5.4.4) and the potential sharing of domestic space. In addition, diseased animals were clearly being consumed, as the butchery marks in close association with some lesions prove (see for example, Figure 9.41). However, at present, if the results are replicated, it can still only be stated that there was a definite *potential* for zoonotic transmission between animals and humans (and vice versa) during this period in time. Until the

disease is demonstrated in humans, it cannot be assumed to be present in the human population.

The horse cranium and atlas from Danebury Hillfort displayed enthesophytes consistent with a possible diagnosis of poll evil (section 4.2.1). If this result is replicated, these lesions, although not directly associated with TB infection, could be used as potential target lesions for the possible identification of TB in horses making the association between poll evil and TB, very much like the documented association of hyperpulmonary osteopathy (HPO) and TB in dogs, as demonstrated by Bathurst & Barta (2004) (section 3.9.2).

The fact that animals were managed and cared for in the Iron Age/Romano-British period is evidenced in some of the more extreme palaeopathological lesions observed at both Danebury Hillfort and Barton Field. At Barton Field, a cattle metacarpal displayed severe, yet healed pathological change associated with m*yostitis ossificans traumatica* (Figure 9.82). This animal was surely lame as a result, yet there was no slaughter of the animal. This suggests the high value placed upon livestock and may be used as potential evidence to suggest that obviously diseased livestock were probably not slaughtered immediately, as they are today. In a review of the animal pathology at Danebury Hillfort, Brothwell (1995) noted a general increase in pathology over time (particularly traumatic pathologies) and suggested that this was due to a change in animal husbandry practice. As an alternative he also considered potential ritual or social interpretations for this

pattern, stating: '*Were less fit animals brought in and sacrificed?*' (Brothwell 1995: 233). This statement leads nicely into a further area of interest that this research has touched upon: the contribution of disease as a reason for the burial/discard of some ABGs. The results of the ABG analyses in this research did not indicate any clear-cut examples of systemic disease – a pattern supported by the summary of ABG pathologies conducted by Morris (2008a). However, the skeleton is only rarely involved if the reported statistics are representative (section 3.8) and the osteological paradox precludes the conclusion that the ABGs were all healthy animals (section 2.5.4). In combination with aDNA analysis, mycolic acid analysis may be able to further explore whether these animals were suffering from an infectious disease. However, with respect of the debate concerning the disposal of these remains, this represents an interesting pattern that requires further analysis.

10.8.4 Viking Age/Norse implications

Just one bone was sampled for aDNA analysis from Hrisheimer, Iceland. Preliminary results amplified spacer 23 on the DR region, characteristic of *M. bovis* (section 9.12.3). This particular bone was excavated from a midden deposit dating to c. 1070-1100 (Phase 3) (Edvardsson pers. comm.). The identification of *M. bovis* in Iceland during this period in time provides numerous implications for further research, especially related to the migration and immigration of people and animals. The Vikings were the first to settle this uninhabited island or 'virgin land'; therefore, this current identification, if substantiated, suggests the disease was introduced by incoming settlers. Identifying the disease in *landnám* fauna would

demonstrate this association more clearly, especially if strontium isotope analysis was also conducted on the affected faunal bones to identify their origin. Transporting animals over long distances and introducing them to new environments is stressful and can result in a lowered immunity (section 5.5.4). Therefore, livestock transported across the North Atlantic would be highly susceptible to infection.

Tuberculosis is suspected in Viking Age human remains in Iceland (section 6.7.2) and also elsewhere in the North Atlantic region, for example, at Westness, Rousay, Orkney (section 6.7.1). Therefore, it is possible that this disease was also endemic in certain regions of the North Atlantic, with some of the smaller islands potentially acting as reservoirs of infection for incoming visitors and/or settlers and their livestock bound for the uninhabited islands of the Faeroes and Iceland. However, the complexities of disease phylogeny and the demonstrated mixed heritage of the North Atlantic region (section 5.5) means that identifying the original source of infection may be difficult. However, being able to demonstrate the presence of *M. bovis* in the domestic animals of Iceland is a start.

10.9 Conclusion

This chapter evaluates this research and, in particular, the preliminary aDNA results in relation to the identification of bTB in zooarchaeological assemblages and its wider research implications for the Iron Age/Romano-British period in southern Britain and the Viking Age/Norse period in Iceland. The establishment of reference

information and the structured classification of lesions are paramount to the retrieval of palaeopathological information from disarticulated assemblages, the mainstay of archaeological research that permits insight into land-use, husbandry practices, diet and population density in past rural society.

11. CONCLUSION AND FURTHER WORK: WORKING TOWARDS DIFFERENTIAL DIAGNOSTIC CRITERIA

'Because adequate palaeopathological diagnostic criteria are lacking, it is difficult to determine whether tuberculosis was present in early animal herds using conventional palaeopathological examination'

(Mays 2005: 128)

11.1 Introduction

The motivation behind this doctoral research was a desire to further explore the relationship shared by humans and animals in the past. The intention was not to focus on the advancements made as a result of this celebrated association, but rather on an inevitable consequence - zoonotic disease.

11.2 Research context: Primary aim and research questions

Tuberculosis has been a scourge of human societies throughout the ages; it stands to reason that bTB was a similar bane of animals, both wild and domestic. Although there is support in the classical literature for the presence of a disease similar to bTB in animals - and also modern cases to support it – its macroscopic identification has remained largely elusive in zoopalaeopathology. However, the number of identified cases in archaeological human remains has flourished because of the existence of a standardised framework of practice and well-established differential

diagnostic criteria. The first identification of *M. bovis* in Iron Age human remains was recently confirmed through aDNA analysis (Taylor *et al.* 2007; Murphy *et al.* 2009), illustrating the successful application of this biomolecular method to the study of human palaeopathology. However, the study of animal disease using both macroscopic and biomolecular methods has been impeded by disarticulated assemblages and the lack of standard recording methods for palaeopathological conditions in animal remains. At present, researchers can draw little confidence that the routine recording of lesions, their consistent description and differential diagnosis will form a part of standard zooarchaeological reports. This research sought to tackle this by combining the disciplines of zooarchaeology, human osteoarchaeology and biomolecular archaeology. The primary aim was to investigate the skeletal appearance of bovine tuberculosis (bTB) in domestic animals, specifically cattle, sheep/goat and pig to produce differential diagnostic criteria for its identification in zooarchaeological assemblages. In order to address this aim, five specific research questions were devised (section 1.5).

11.3 Lesion morphology

Although bTB is a significant health problem in modern wild and domesticated animals, pictorial and written reference information related to its skeletal manifestation in faunal remains is limited. In order to investigate lesion morphology, a small number of early 20th century illustrations were analysed, in addition to documented modern case-studies involving skeletal tuberculosis. These were informative and highlighted two key differences between the osteological appearance and location of lesions in animal and human bone:

- A greater emphasis on bone proliferation in animal bone compared to human bone. The lesions of TB are predominantly osteolytic in humans.
- Involvement of the neural arch and spinous process in animal bone, specifically evident in pigs and horses. The posterior parts of the vertebrae are rarely involved in humans.

In addition to highlighted differences, the documented association between osteomyelitis and tuberculous infection was also supported.

11.4 Lesion specificity

Lesion specificity was investigated using aDNA analysis. It became evident early in the research that the limited way in which bone reacts to infection clouds the identification of pathognomonic lesions, both in human and faunal bone. However, the application of aDNA analysis has proved to be a promising complementary tool with the potential to further our appreciation of the skeletal manifestation of this disease in animals, as well as to provide a greater understanding of disease frequency in past animal populations. The preliminary results of the aDNA analysis, if successfully replicated, represent the beginnings of a reference dataset. The addition of positive results from bones with a host of different lesion types would enable patterns to be identified and tentative associations made. Through the continued combination of these disciplines, it is hoped that zoopalaeopathology will progress to the state where it, too, can state '*...we are left with lesions that are 'consistent with' a diagnosis of TB but also consistent with other conditions.'* (Wilbur

et al. 2009: 1991). At first glance, this would not appear to represent 'progress'; on the contrary, this would represent a substantial development in zoopalaeopathology, one which would provide a foundation for considerable further research.

11.5 Lesion distribution and differential diagnosis

This research implemented skeletal lesion patterning and differential diagnosis, methods regularly employed in human palaeopathology. Illustrations presenting the distribution of lesions and lesion predilection sites for cattle, pig and humans were created for use alongside a series of reference tables for those pathological conditions that may osteologically mimic MTB complex disease. The illustrations provide a useful visual aid, for use in the process of differential diagnosis by highlighting obvious differences in lesion location between species. These differences can then be further compared and contrasted using the reference tables. In cattle, pigs and humans the cancellous bone regions of the axial and appendicular skeleton are targeted most frequently. This was a consistent pattern identified throughout the research with the majority of pathological lesions recorded on ABGs and also on the disarticulated bones favouring these regions. One specific difference highlighted between cattle and pig in relation to bTB is the preference for involvement of the pelvis in pigs. The distribution of those lesions identified as possibly reflecting infection – non-specific proliferation and bone lysis - were statistically tested using chi-square analysis. Non-specific proliferation, primarily periostosis, was consistently located in the appendicular region and non-specific lysis in the axial region.

11.6 Non-specific lesion classification and categorisation

The provision of a solid basis for lesion classification and differential diagnosis was found to provide the means for a better appreciation of the levels of potential infection in past animal populations, allowing for a crude prevalence to be calculated. The two lesion types identified as potentially demonstrating infection (see section 11.5) were compared and contrasted by species, site and time period using chi-square statistical analyses. A number of significant differences were noted at $\alpha = 0.05$. However, those differences found to be insignificant were just as informative. The classification of these particular lesion types also acted as a guide, highlighting particular lesion types, for example, enlarged foramina in vertebrae, for potential further biomolecular analyses. A total of six disarticulated bones (two modern and four archaeological) were submitted for aDNA analysis. The preliminary results indicate *M. bovis* in all six, with the strongest result associated with a large terrestrial mammal lumbar vertebra from Danebury Hillfort. These are currently undergoing replication at a second centre.

11.7 Human palaeopathology and zoopalaeopathology: A common ground?

This research demonstrates that zoopalaeopathology would benefit from a more standardised approach to the recording and classification of pathological lesions, specifically those that may indicate specific infection. The approach used in this research draws upon methods commonplace in human palaeopathology and applies them to zooarchaeological assemblages. Although the objectives for each discipline and the circumstances of bone preservation differ, the reaction of bone to insult, injury and disease remains the same. This research identifies a common

ground, where methods formulated for use in human palaeopathology, complemented by biomolecular analyses, can be successfully adapted for use in zoopalaeopathology.

11.8 Research results: Was the primary aim achieved?

The results of this research emphasise the difficulties associated with the identification of systemic diseases in zooarchaeological assemblages. Although bTB has yet to be formally confirmed in archaeological faunal remains and the association of osseous lesions to this disease requires more research and a substantially larger dataset, the primary aim was achieved in part. The skeletal appearance of bTB in domestic animals was thoroughly investigated providing valuable reference information for future researchers. This information has formed a solid foundation for the development of differential diagnostic criteria by demonstrating key differences between humans and animals in the reaction of bone to this disease and skeletal predilection sites. This represents a significant step towards the future identification of bTB in archaeological animal bone and, therefore, represents the beginning of an exciting journey for zoopalaeopathology.

11.9 Further work: The way forward

The potential to explore palaeoepidemiology and learn more about the frequency of different animal diseases in the past, specifically zoonotic diseases like bTB, is important not only for zooarchaeology but also for human palaeopathology. The fundamental change in settlement lifestyle that saw hunter-gatherers settle down

and pursue agriculture and animal husbandry also placed them into prolonged contact with animals. This left behind a legacy – zoonotic disease. Some of the most notorious human diseases of modern times emerged from zoonotic pathogens, for example, bovine spongiform encephalopathy (BSE) and human immunodeficiency virus (HIV) (Murphy 1998: 430). The inability to differentiate between the bovine and human strains of tuberculosis has led to an underestimation of the prevalence of bTB in both the present day and the distant past. However, the application of aDNA to the study of palaeopathology is challenging this misconception, as the recent identifications of *M. bovis* in Iron Age human remains attest. The results of this research have the potential to add weight to this, helping to pave the way towards a more refined appreciation of systemic animal disease in the past.

There are several potential areas for further work that would aid in the development of this research. These are listed below:

- The application of lipid biomarker analysis, specifically mycolic acid analysis as a complementary tool alongside aDNA analysis to aid in the identification of bTB in both human and animal remains
- The implementation of strontium isotope analysis on confirmed cases of bTB in faunal remains, particularly in the Viking Age North Atlantic region (specifically Iceland) to pinpoint the origins of diseased livestock
- The analysis of wild species in zooarchaeological assemblages to further explore the potential for reservoirs of infection in past societies

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Appendix 1 – 2009 stats

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Appendix 2 – 2010 stats

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Ancient DNA (aDNA) Analysis of Animal Bones with a Possible Diagnosis of Tuberculosis.

Statistics Appendix

Wetwang Slack:

1) The frequency of cattle vs. sheep/goat pathology in the Iron Age phase at Wetwang Slack

H_0 The frequency of pathological cattle bones is equal to the frequency of pathological sheep/goat bones in the Iron Age phase at Wetwang Slack

H_1 The frequency of pathological cattle bones is different to the frequency of pathological sheep/goat bones in the Iron Age phase at Wetwang Slack

$X^2 = .0621$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	45	841	886
Percent of total	2.084%	38.953%	41.038%
Frequencies, row 2	44	1229	1273
Percent of total	2.038%	56.925%	58.962%
Column totals	89	2070	2159
Percent of total	4.122%	95.878%	
Chi-square (df=1)	3.48	p= .0621	
V-square (df=1)	3.48	p= .0622	
Yates corrected Chi-square	3.08	p= .0792	
Phi-square	.00161		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1098.50	p=0.0000	
Chi-square (B/C)	715.95	p=0.0000	

2) The frequency of cattle vs. sheep/goat oral pathology in the Iron Age phase at Wetwang Slack

H_0 The frequency of oral pathology in cattle is equal to the frequency of oral pathology in sheep/goat in the Iron Age phase at Wetwang Slack

H_1 The frequency of oral pathology in cattle is different to the frequency of oral pathology in sheep/goat in the Iron Age phase at Wetwang Slack

$X^2 = .0146$, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	7	879	886
Percent of total	.324%	40.713%	41.038%
Frequencies, row 2	27	1246	1273
Percent of total	1.251%	57.712%	58.962%
Column totals	34	2125	2159
Percent of total	1.575%	98.425%	
Chi-square (df=1)	5.97	p= .0146	
V-square (df=1)	5.97	p= .0146	
Yates corrected Chi-square	5.14	p= .0234	
Phi-square	.00277		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1223.18	p=0.0000	
Chi-square (B/C)	799.34	p=0.0000	

3) The frequency of cattle vs. sheep/goat arthropathy in the Iron Age phase at Wetwang Slack

H_0 The frequency of arthropathy in cattle is equal to the frequency of arthropathy in sheep/goat in the Iron Age phase at Wetwang Slack

H_1 The frequency of arthropathy in cattle is different to the frequency of arthropathy in sheep/goat in the Iron Age phase at Wetwang Slack

$X^2 = .0001$, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	16	870	886
Percent of total	.741%	40.296%	41.038%
Frequencies, row 2	3	1270	1273
Percent of total	.139%	58.824%	58.962%
Column totals	19	2140	2159
Percent of total	.880%	99.120%	
Chi-square (df=1)	14.77	p= .0001	
V-square (df=1)	14.76	p= .0001	
Yates corrected Chi-square	13.02	p= .0003	
Phi-square	.00684		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1220.85	p=0.0000	
Chi-square (B/C)	859.06	p=0.0000	

4) The frequency of cattle vs. sheep/goat non-specific bone proliferation in the Iron Age phase at Wetwang Slack

H_0 The frequency of non-specific bone proliferation in cattle is equal to the frequency of non-specific bone proliferation in sheep/goat in the Iron Age phase at Wetwang Slack

or

There is no significant difference between the frequency of non-specific bone proliferation in cattle and sheep/goat in the Iron Age phase at Wetwang Slack

H_1 The frequency of non-specific bone proliferation in cattle is different to the frequency of non-specific bone proliferation in sheep/goat in the Iron Age phase at Wetwang Slack

There is a significant difference between the frequency of non-specific bone proliferation in cattle and sheep/goat in the Iron Age phase at Wetwang Slack

$X^2 = .6721$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	10	876	886
Percent of total	.463%	40.574%	41.038%
Frequencies, row 2	12	1261	1273
Percent of total	.556%	58.407%	58.962%
Column totals	22	2137	2159
Percent of total	1.019%	98.981%	
Chi-square (df=1)	.18	p= .6721	
V-square (df=1)	.18	p= .6721	
Yates corrected Chi-square	.04	p= .8372	
Phi-square	.00008		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1229.35	p=0.0000	
Chi-square (B/C)	838.70	p=0.0000	

With ltm and mtm included

4b) The frequency of cattle vs. sheep/goat non-specific bone proliferation in the Iron Age phase at Wetwang Slack

H_0 The frequency of non-specific bone proliferation in cattle is equal to the frequency of non-specific bone proliferation in sheep/goat in the Iron Age phase at Wetwang Slack

or

There is no significant difference between the frequency of non-specific bone proliferation in cattle and sheep/goat in the Iron Age phase at Wetwang Slack

H_1 The frequency of non-specific bone proliferation in cattle is different to the frequency of non-specific bone proliferation in sheep/goat in the Iron Age phase at Wetwang Slack

There is a significant difference between the frequency of non-specific bone proliferation in cattle and sheep/goat in the Iron Age phase at Wetwang Slack

$X^2 = .7948$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	14	4529	4543
Percent of total	.110%	35.681%	35.791%
Frequencies, row 2	23	8127	8150
Percent of total	.181%	64.027%	64.209%
Column totals	37	12656	12693
Percent of total	.291%	99.709%	
Chi-square (df=1)	.07	p= .7948	
V-square (df=1)	.07	p= .7948	
Yates corrected Chi-square	.01	p= .9296	
Phi-square	.00001		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	8083.10	p=0.0000	
Chi-square (B/C)	4458.48	p=0.0000	

4) The frequency of cattle vs. sheep/goat non-specific bone lysis in the Iron Age phase at Wetwang Slack

H_0 The frequency of non-specific bone lysis in cattle is equal to the frequency of non-specific bone lysis in sheep/goat in the Iron Age phase at Wetwang Slack

or

There is no significant difference between the frequency of non-specific bone lysis in cattle and sheep/goat in the Iron Age phase at Wetwang Slack

H_1 The frequency of non-specific bone lysis in cattle is different to the frequency of non-specific bone lysis in sheep/goat in the Iron Age phase at Wetwang Slack

There is a significant difference between the frequency of non-specific bone lysis in cattle and sheep/goat in the Iron Age phase at Wetwang Slack

$X^2 = .0004$, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	11	875	886
Percent of total	.509%	40.528%	41.038%
Frequencies, row 2	1	1272	1273
Percent of total	.046%	58.916%	58.962%
Column totals	12	2147	2159
Percent of total	.556%	99.444%	
Chi-square (df=1)	12.78	p= .0004	
V-square (df=1)	12.78	p= .0004	
Yates corrected Chi-square	10.77	p= .0010	
Phi-square	.00592		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1237.41	p=0.0000	
Chi-square (B/C)	870.01	p=0.0000	

With ltm and mtm included

4b) The frequency of cattle vs. sheep/goat non-specific bone lysis in the Iron Age phase at Wetwang Slack

H_0 The frequency of non-specific bone lysis in cattle is equal to the frequency of non-specific bone lysis in sheep/goat in the Iron Age phase at Wetwang Slack

or

There is no significant difference between the frequency of non-specific bone lysis in cattle and sheep/goat in the Iron Age phase at Wetwang Slack

H_1 The frequency of non-specific bone lysis in cattle is different to the frequency of non-specific bone lysis in sheep/goat in the Iron Age phase at Wetwang Slack

There is a significant difference between the frequency of non-specific bone lysis in cattle and sheep/goat in the Iron Age phase at Wetwang Slack

$X^2 = .0004$, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	12	4531	4543
Percent of total	.095%	35.697%	35.791%
Frequencies, row 2	3	8147	8150
Percent of total	.024%	64.185%	64.209%
Column totals	15	12678	12693
Percent of total	.118%	99.882%	
Chi-square (df=1)	12.77	p= .0004	
V-square (df=1)	12.77	p= .0004	
Yates corrected Chi-square	10.92	p= .0010	
Phi-square	.00101		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	8109.08	p=0.0000	
Chi-square (B/C)	4520.01	p=0.0000	

X) *The frequency of NSBP vs. NSBL for s/g in the IA phase at Wetwang Slack*

H_0 There is no significant difference between the frequency of NSBP and NSBL for s/g in the IA phase at Wetwang Slack

H_1 There is a significant difference between the frequency of NSBP and NSBL for s/g in the IA phase at Wetwang Slack

$X^2 = .0022$, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	12	1261	1273
Percent of total	.471%	49.529%	50.000%
Frequencies, row 2	1	1272	1273
Percent of total	.039%	49.961%	50.000%
Column totals	13	2533	2546
Percent of total	.511%	99.489%	
Chi-square (df=1)	9.36	p= .0022	
V-square (df=1)	9.35	p= .0022	
Yates corrected Chi-square	7.73	p= .0054	
Phi-square	.00367		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1234.49	p=0.0000	
Chi-square (B/C)	1256.01	p=0.0000	

X) *The frequency of NSBP vs. NSBL for cattle in the IA phase at Wetwang Slack*

H_0 There is no significant difference between the frequency of NSBP and NSBL for cattle in the IA phase at Wetwang Slack

H_1There is a significant difference between the frequency of NSBP and NSBL for cattle in the IA phase at Wetwang Slack

$X^2 = 1.0000$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	10	876	886
Percent of total	.564%	49.436%	50.000%
Frequencies, row 2	10	876	886
Percent of total	.564%	49.436%	50.000%
Column totals	20	1752	1772
Percent of total	1.129%	98.871%	
Chi-square (df=1)	0.00	p=1.000(	
V-square (df=1)	0.00	p=1.000(	
Yates corrected Chi-square	.05	p= .8221	
Phi-square	0.0000(		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	844.5(	p=0.000(	
Chi-square (B/C)	844.5(	p=0.000(	

X) *The frequency of NSBP vs. NSBL for s/g in the IA/RB phase at Wetwang Slack*

H_0 There is no significant difference between the frequency of NSBP and NSBL for s/g in the IA/rb phase at Wetwang Slack

H_1There is a significant difference between the frequency of NSBP and NSBL for s/g in the IA/rb phase at Wetwang Slack

$X^2 = .1562$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	6	723	729
Percent of total	.412%	49.588%	50.000%
Frequencies, row 2	2	727	729
Percent of total	.137%	49.863%	50.000%
Column totals	8	1450	1458
Percent of total	.549%	99.451%	
Chi-square (df=1)	2.01	p= .1562	
V-square (df=1)	2.01	p= .1563	
Yates corrected Chi-square	1.13	p= .2875	
Phi-square	.00138		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	707.23	p=0.0000	
Chi-square (B/C)	715.03	p=0.0000	

5) *The frequency of cattle vs. sheep/goat pathology in the Iron Age/* Romano-British phase *phase at Wetwang Slack*

H_0 There is no significant difference between the frequency of pathological cattle bones and sheep/goat bones in the Iron Age/Romano-British phase at Wetwang Slack

H_1 There is a significant difference between the frequency of pathological cattle bones and sheep/goat bones in the Iron Age/Romano-British phase at Wetwang Slack

$X^2 = .1319$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	41	688	729
Percent of total	4.801%	80.562%	85.363%
Frequencies, row 2	3	122	125
Percent of total	.351%	14.286%	14.637%
Column totals	44	810	854
Percent of total	5.152%	94.848%	
Chi-square (df=1)	2.27	p= .1319	
V-square (df=1)	2.27	p= .1322	
Yates corrected Chi-square	1.66	p= .1979	
Phi-square	.00266		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	39.26	p= .0000	
Chi-square (B/C)	677.07	p=0.0000	

6) *The frequency of sheep/goat oral pathology in the Iron Age and Iron Age/Romano-British phase at Wetwang Slack*

H_0 There is no significant difference between the frequency of sheep/goat oral pathology between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

H_1 There is a significant difference between the frequency of sheep/goat oral pathology between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

$X^2 = .7567$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	27	1246	1273
Percent of total	1.349%	62.238%	63.586%
Frequencies, row 2	17	712	729
Percent of total	.849%	35.564%	36.414%
Column totals	44	1958	2002
Percent of total	2.198%	97.802%	
Chi-square (df=1)	.10	p= .7567	
V-square (df=1)	.10	p= .7567	
Yates corrected Chi-square	.02	p= .8796	
Phi-square	.00005		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	633.09	p=0.0000	
Chi-square (B/C)	1193.97	p=0.0000	

7) *The frequency of sheep/goat trauma in the Iron Age and Iron Age/Romano-British phase at Wetwang Slack*

H_0 There is no significant difference between the frequency of sheep/goat trauma between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

H_1 There is a significant difference between the frequency of sheep/goat trauma between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

$X^2 = .0041$, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	2	1271	1273
Percent of total	.100%	63.487%	63.586%
Frequencies, row 2	8	721	729
Percent of total	.400%	36.014%	36.414%
Column totals	10	1992	2002
Percent of total	.500%	99.501%	
Chi-square (df=1)	8.25	p= .0041	
V-square (df=1)	8.24	p= .0041	
Yates corrected Chi-square	6.46	p= .0110	
Phi-square	.00412		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	713.03	p=0.0000	
Chi-square (B/C)	1245.23	p=0.0000	

8) *The frequency of sheep/goat arthropathy in the Iron Age and Iron Age/Romano-British phase at Wetwang Slack*

H_0 There is no significant difference between the frequency of sheep/goat arthropathy between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

H_1 There is a significant difference between the frequency of sheep/goat arthropathy between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

$X^2 = .2758$, $p > 0.05$, d.f. = 1

H_0 is accepted $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	1	1272	1273
Percent of total	.050%	63.536%	63.586%
Frequencies, row 2	2	727	729
Percent of total	.100%	36.314%	36.414%
Column totals	3	1999	2002
Percent of total	.150%	99.850%	
Chi-square (df=1)	1.19	p= .2758	
V-square (df=1)	1.19	p= .2759	
Yates corrected Chi-square	.24	p= .6246	
Phi-square	.00059		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	722.01	p=0.0000	
Chi-square (B/C)	1264.02	p=0.0000	

9) *The frequency of sheep/goat NSBP in the Iron Age and Iron Age/Romano-British phase at Wetwang Slack*

H_0 There is no significant difference between the frequency of sheep/goat NSBP between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

H_1There is a significant difference between the frequency of sheep/goat NSBP between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

$X^2 = .7850$, $p > 0.05$, d.f. = 1

H_0 is accepted $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	12	1261	1273
Percent of total	.599%	62.987%	63.586%
Frequencies, row 2	6	723	729
Percent of total	.300%	36.114%	36.414%
Column totals	18	1984	2002
Percent of total	.899%	99.101%	
Chi-square (df=1)	.07	p= .785(	
V-square (df=1)	.07	p= .785(	
Yates corrected Chi-square	.00	p= .978(	
Phi-square	.00004		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	685.85	p=0.000(	
Chi-square (B/C)	1241.13	p=0.000(	

10) *The frequency of sheep/goat NSBL in the Iron Age and Iron Age/Romano-British phase at Wetwang Slack*

H_0 There is no significant difference between the frequency of sheep/goat NSBL between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

H_1 There is a significant difference between the frequency of sheep/goat NSBL between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

$X^2 = .2758$, $p > 0.05$, d.f. = 1

H_0 is accepted $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	1	1272	1273
Percent of total	.050%	63.536%	63.586%
Frequencies, row 2	2	727	729
Percent of total	.100%	36.314%	36.414%
Column totals	3	1999	2002
Percent of total	.150%	99.850%	
Chi-square (df=1)	1.19	p= .275(	
V-square (df=1)	1.19	p= .275(	
Yates corrected Chi-square	.24	p= .624(	
Phi-square	.00059		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	722.01	p=0.000(	
Chi-square (B/C)	1264.02	p=0.000(	

11) *The frequency of sheep/goat 'other' in the Iron Age and Iron Age/Romano-British phase at Wetwang Slack*

H_0 There is no significant difference between the frequency of sheep/goat other between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

H_1There is a significant difference between the frequency of sheep/goat other between the Iron Age and Iron Age/Romano-British phases at Wetwang Slack

$X^2 = .0538$, $p > 0.05$, d.f. = 1

H_0 is accepted $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	2	1271	1273
Percent of total	.100%	63.487%	63.586%
Frequencies, row 2	5	724	729
Percent of total	.250%	36.164%	36.414%
Column totals	7	1995	2002
Percent of total	.350%	99.650%	
Chi-square (df=1)	3.72	p= .0538	
V-square (df=1)	3.72	p= .0538	
Yates corrected Chi-square	2.36	p= .1247	
Phi-square	.00186		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	716.03	p=0.0000	
Chi-square (B/C)	1254.09	p=0.0000	

12) *The frequency of cattle vs. sheep/goat pathology at Barton Field*

H_0 There is no significant difference between the frequency of pathological cattle bones and sheep/goat bones at Barton Field

H_1There is a significant difference between the frequency of pathological cattle bones and sheep/goat bones at Barton Field

$X^2 = .0002$, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	21	267	288
Percent of total	1.845%	23.462%	25.308%
Frequencies, row 2	21	829	850
Percent of total	1.845%	72.847%	74.692%
Column totals	42	1096	1138
Percent of total	3.691%	96.309%	
Chi-square (df=1)	14.07	p= .0002	
V-square (df=1)	14.05	p= .0002	
Yates corrected Chi-square	12.74	p= .0004	
Phi-square	.01236		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	766.18	p=0.0000	
Chi-square (B/C)	208.42	p=0.0000	

13) *The frequency of cattle vs. sheep/goat oral pathology at Barton Field*

H_0 There is no significant difference between the frequency of cattle and sheep/goat oral pathology at Barton Field

H_1There is a significant difference between the frequency of cattle and sheep/goat oral pathology at Barton Field

$X^2 = .7317$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	285	288
Percent of total	.264%	25.044%	25.308%
Frequencies, row 2	7	843	850
Percent of total	.615%	74.077%	74.692%
Column totals	10	1128	1138
Percent of total	.879%	99.121%	
Chi-square (df=1)	.12	p= .7317	
V-square (df=1)	.12	p= .7319	
Yates corrected Chi-square	.00	p= .9821	
Phi-square	.00010		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	832.06	p=0.0000	
Chi-square (B/C)	262.77	p=0.0000	

14) *The frequency of cattle vs. sheep/goat trauma at Barton Field*

H_0 There is no significant difference between the frequency of cattle and sheep/goat trauma at Barton Field

H_1 There is a significant difference between the frequency of cattle and sheep/goat trauma at Barton Field

$X^2 = .4215$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	1	287	288
Percent of total	.088%	25.220%	25.308%
Frequencies, row 2	1	849	850
Percent of total	.088%	74.605%	74.692%
Column totals	2	1136	1138
Percent of total	.176%	99.824%	
Chi-square (df=1)	.65	p= .4215	
V-square (df=1)	.65	p= .4217	
Yates corrected Chi-square	.00	p= .9920	
Phi-square	.00057		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	844.01	p=0.0000	
Chi-square (B/C)	282.03	p=0.0000	

15) *The frequency of cattle vs. sheep/goat NSBP at Barton Field*

H_0 There is no significant difference between the frequency of cattle and sheep/goat NSBP at Barton Field

H_1 There is a significant difference between the frequency of cattle and sheep/goat NSBP at Barton Field

$X^2 = .2841$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	285	288
Percent of total	.264%	25.044%	25.308%
Frequencies, row 2	4	846	850
Percent of total	.351%	74.341%	74.692%
Column totals	7	1131	1138
Percent of total	.615%	99.385%	
Chi-square (df=1)	1.15	p= .2841	
V-square (df=1)	1.15	p= .2843	
Yates corrected Chi-square	.40	p= .5253	
Phi-square	.00101		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	835.06	p=0.0000	
Chi-square (B/C)	271.28	p=0.0000	

16) *The frequency of cattle vs. sheep/goat NSBL at Barton Field*

H_0 There is no significant difference between the frequency of cattle and sheep/goat NSBL at Barton Field

H_1There is a significant difference between the frequency of cattle and sheep/goat NSBL at Barton Field

$X^2 = .0010$, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	5	283	288
Percent of total	.439%	24.868%	25.308%
Frequencies, row 2	1	849	850
Percent of total	.088%	74.605%	74.692%
Column totals	6	1132	1138
Percent of total	.527%	99.473%	
Chi-square (df=1)	10.74	p= .0010	
V-square (df=1)	10.73	p= .0011	
Yates corrected Chi-square	7.88	p= .0050	
Phi-square	.00944		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	832.14	p=0.0000	
Chi-square (B/C)	278.03	p=0.0000	

17) *The frequency of cattle vs. sheep/goat other at Barton Field*

H_0 There is no significant difference between the frequency of cattle and sheep/goat ocm at Barton Field

H_1There is a significant difference between the frequency of cattle and sheep/goat ocm at Barton Field

X^2 = .5849, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	2	286	288
Percent of total	.176%	25.132%	25.308%
Frequencies, row 2	9	841	850
Percent of total	.791%	73.902%	74.692%
Column totals	11	1127	1138
Percent of total	.967%	99.033%	
Chi-square (df=1)	.30	p= .5849	
V-square (df=1)	.30	p= .5851	
Yates corrected Chi-square	.04	p= .8432	
Phi-square	.00026		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	833.03	p=0.0000	
Chi-square (B/C)	258.22	p=0.0000	

17) *The frequency of NSBP vs. NSBL for cattle at Barton Field*

H_0 There is no significant difference between the frequency of NSBP and NSBL for cattle at Barton Field

H_1There is a significant difference between the frequency of NSBP and NSBL for cattle at Barton Field

X^2 = .4764, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	285	288
Percent of total	.521%	49.479%	50.000%
Frequencies, row 2	5	283	288
Percent of total	.868%	49.132%	50.000%
Column totals	8	568	576
Percent of total	1.389%	98.611%	
Chi-square (df=1)	.51	p= .4764	
V-square (df=1)	.51	p= .4768	
Yates corrected Chi-square	.13	p= .7218	
Phi-square	.00088		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	272.17	p=0.0000	
Chi-square (B/C)	268.42	p=0.0000	

17) *The frequency of NSBP vs. NSBL for s/g at Barton Field*

H_0 There is no significant difference between the frequency of NSBP and NSBL for s/g at Barton Field

H_1There is a significant difference between the frequency of NSBP and NSBL for s/g at Barton Field

$X^2 = .1791$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	4	846	850
Percent of total	.235%	49.765%	50.000%
Frequencies, row 2	1	849	850
Percent of total	.059%	49.941%	50.000%
Column totals	5	1695	1700
Percent of total	.294%	99.706%	
Chi-square (df=1)	1.81	p= .1791	
V-square (df=1)	1.80	p= .1792	
Yates corrected Chi-square	.80	p= .3704	
Phi-square	.00106		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	835.09	p=0.0000	
Chi-square (B/C)	841.01	p=0.0000	

x) *The frequency of cattle vs. sheep/goat pathology at Westness*

H_0 There is no significant difference between the frequency of pathological cattle bones and sheep/goat bones at Westness

H_1There is a significant difference between the frequency of pathological cattle bones and sheep/goat bones at Westness

X^2 = .1164, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	19	851	870
Percent of total	.963%	43.154%	44.118%
Frequencies, row 2	14	1088	1102
Percent of total	.710%	55.172%	55.882%
Column totals	33	1939	1972
Percent of total	1.673%	98.327%	
Chi-square (df=1)	2.47	p= .1164	
V-square (df=1)	2.46	p= .1165	
Yates corrected Chi-square	1.94	p= .1635	
Phi-square	.00125		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1030.37	p=0.0000	
Chi-square (B/C)	807.97	p=0.0000	

x) *The frequency of cattle vs. sheep/goat oral pathology at Westness*

H_0 There is no significant difference between the frequency of cattle and sheep/goat oral pathology at Westness

H_1There is a significant difference between the frequency of cattle and sheep/goat oral pathology at Westness

X^2 = .1750, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	1	869	870
Percent of total	.051%	44.067%	44.118%
Frequencies, row 2	5	1097	1102
Percent of total	.254%	55.629%	55.882%
Column totals	6	1966	1972
Percent of total	.304%	99.696%	
Chi-square (df=1)	1.84	p= .175(	
V-square (df=1)	1.84	p= .1751	
Yates corrected Chi-square	.89	p= .344(	
Phi-square	.00093		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1092.01	p=0.000(	
Chi-square (B/C)	852.14	p=0.000(	

x) *The frequency of cattle vs. sheep/goat other at Westness*

H_0 There is no significant difference between the frequency of cattle and sheep/goat other at Westness

H_1 There is a significant difference between the frequency of cattle and sheep/goat other at Westness

$X^2 = .7056$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	1	869	870
Percent of total	.051%	44.067%	44.118%
Frequencies, row 2	4	1098	1102
Percent of total	.203%	55.680%	55.882%
Column totals	5	1967	1972
Percent of total	.254%	99.746%	
Chi-square (df=1)	1.18	p= .276(	
V-square (df=1)	1.18	p= .276(	
Yates corrected Chi-square	.41	p= .524(	
Phi-square	.00060		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1093.01	p=0.000(	
Chi-square (B/C)	855.09	p=0.000(	

x) *The frequency of cattle vs. sheep/goat pathology at Hofstaðir*

H_0 There is no significant difference between the frequency of pathological cattle bones and sheep/goat bones at *Hofstaðir*

H_1There is a significant difference between the frequency of pathological cattle bones and sheep/goat bones at *Hofstaðir*

X^2 = .7051, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	134	6288	6422
Percent of total	1.570%	73.664%	75.234%
Frequencies, row 2	47	2067	2114
Percent of total	.551%	24.215%	24.766%
Column totals	181	8355	8536
Percent of total	2.120%	97.880%	
Chi-square (df=1)	.14	p= .7051	
V-square (df=1)	.14	p= .7051	
Yates corrected Chi-square	.08	p= .7708	
Phi-square	.00002		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1695.88	p=0.0000	
Chi-square (B/C)	6146.42	p=0.0000	

x) *The frequency of cattle vs. sheep/goat trauma at Hofstaðir*

H_0 There is no significant difference between the frequency of cattle and sheep/goat *trauma* at *Hofstaðir*

H_1There is a significant difference between the frequency of cattle and sheep/goat *trauma* at *Hofstaðir*

X^2 = .8472, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	2111	2114
Percent of total	.035%	24.731%	24.766%
Frequencies, row 2	8	6414	6422
Percent of total	.094%	75.141%	75.234%
Column totals	11	8525	8536
Percent of total	.129%	99.871%	
Chi-square (df=1)	.04	p= .8472	
V-square (df=1)	.04	p= .8472	
Yates corrected Chi-square	.02	p= .8755	
Phi-square	.00000		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6403.01	p=0.0000	
Chi-square (B/C)	2085.14	p=0.0000	

x) *The frequency of cattle vs. sheep/goat arthropathy at Hofstaðir*

H_0 There is no significant difference between the frequency of cattle and sheep/goat *arthropathy* at *Hofstaðir*

H_1There is a significant difference between the frequency of cattle and sheep/goat *arthropathy* at *Hofstaðir*

$X^2 = .0000$, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	36	2078	2114
Percent of total	.422%	24.344%	24.766%
Frequencies, row 2	1	6421	6422
Percent of total	.012%	75.223%	75.234%
Column totals	37	8499	8536
Percent of total	.433%	99.567%	
Chi-square (df=1)	104.92	p=0.0000	
V-square (df=1)	104.91	p=0.0000	
Yates corrected Chi-square	101.05	p=0.0000	
Phi-square	.01229		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6311.83	p=0.0000	
Chi-square (B/C)	2073.00	p=0.0000	

x) *The frequency of cattle vs. sheep/goat congenital at Hofstaðir*

H_0 There is no significant difference between the frequency of cattle and sheep/goat *congenital* at *Hofstaðir*

H_1There is a significant difference between the frequency of cattle and sheep/goat *congenital* at *Hofstaðir*

$X^2 = .0174$, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	4	2110	2114
Percent of total	.047%	24.719%	24.766%
Frequencies, row 2	2	6420	6422
Percent of total	.023%	75.211%	75.234%
Column totals	6	8530	8536
Percent of total	.070%	99.930%	
Chi-square (df=1)	5.66	p= .0174	
V-square (df=1)	5.66	p= .0174	
Yates corrected Chi-square	3.63	p= .0567	
Phi-square	.00066		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6406.01	p=0.0000	
Chi-square (B/C)	2102.01	p=0.0000	

x) *The frequency of cattle vs. sheep/goat NSBP at Hofstaðir*

H_0 There is no significant difference between the frequency of cattle and sheep/goat *NSBP* at *Hofstaðir*

H_1There is a significant difference between the frequency of cattle and sheep/goat *NSBP* at *Hofstaðir.*

$X^2 = .8831$, $p > 0.05$, d.f. = 1

H_0 is ACCEPTED at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	6	2108	2114
Percent of total	.070%	24.695%	24.766%
Frequencies, row 2	17	6405	6422
Percent of total	.199%	75.035%	75.234%
Column totals	23	8513	8536
Percent of total	.269%	99.731%	
Chi-square (df=1)	.02	p= .8831	
V-square (df=1)	.02	p= .8831	
Yates corrected Chi-square	.01	p= .9244	
Phi-square	.00000		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6385.03	p=0.0000	
Chi-square (B/C)	2055.58	p=0.0000	

x) *The frequency of cattle vs. sheep/goat NSBl at Hofstaðir*

H_0 There is no significant difference between the frequency of cattle and sheep/goat *NSBL* at *Hofstaðir*

H_1There is a significant difference between the frequency of cattle and sheep/goat *NSBL* at *Hofstaðir.*

$X^2 = .8472$, $p > 0.05$, d.f. = 1

H_0 is ACCEPTED at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	2111	2114
Percent of total	.035%	24.731%	24.766%
Frequencies, row 2	8	6414	6422
Percent of total	.094%	75.141%	75.234%
Column totals	11	8525	8536
Percent of total	.129%	99.871%	
Chi-square (df=1)	.04	p= .8472	
V-square (df=1)	.04	p= .8472	
Yates corrected Chi-square	.02	p= .8755	
Phi-square	.00000		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6403.01	p=0.0000	
Chi-square (B/C)	2085.14	p=0.0000	

x) *The frequency of cattle vs. sheep/goat ocd at Hofstaðir*

H_0 There is no significant difference between the frequency of cattle and sheep/goat *OCD* at *Hofstaðir*

H_1There is a significant difference between the frequency of cattle and sheep/goat *ocd* at *Hofstaðir.*

$X^2 = .3111$, $p > 0.05$, d.f. = 1

H_0 is ACCEPTED at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	2111	2114
Percent of total	.035%	24.731%	24.766%
Frequencies, row 2	17	6405	6422
Percent of total	.199%	75.035%	75.234%
Column totals	20	8516	8536
Percent of total	.234%	99.766%	
Chi-square (df=1)	1.03	p= .3111	
V-square (df=1)	1.03	p= .3111	
Yates corrected Chi-square	.57	p= .4511	
Phi-square	.00012		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6394.01	p=0.0000	
Chi-square (B/C)	2058.58	p=0.0000	

x) *The frequency of NSBP vs. NSBL for s/g at Hofstaðir*

H_0 There is no significant difference between the frequency of NSBP and NSBL for s/g at *Hofstaðir*

H_1There is a significant difference between the frequency of NSBP and NSBL for s/g at *Hofstaðir*

$X^2 = .0716$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	17	6405	6422
Percent of total	.132%	49.868%	50.000%
Frequencies, row 2	8	6414	6422
Percent of total	.062%	49.938%	50.000%
Column totals	25	12819	12844
Percent of total	.195%	99.805%	
Chi-square (df=1)	3.25	p= .0716	
V-square (df=1)	3.25	p= .0716	
Yates corrected Chi-square	2.56	p= .1093	
Phi-square	.00025		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6361.19	p=0.0000	
Chi-square (B/C)	6379.04	p=0.0000	

x) *The frequency of NSBP vs. NSBL for cattle at Hofstaðir*

H_0 There is no significant difference between the frequency of NSBP and NSBL for cattle at *Hofstaðir*

H_1 There is a significant difference between the frequency of NSBP and NSBL for cattle at *Hofstaðir*

$X^2 = .3168$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	6	2108	2114
Percent of total	.142%	49.858%	50.000%
Frequencies, row 2	3	2111	2114
Percent of total	.071%	49.929%	50.000%
Column totals	9	4219	4228
Percent of total	.213%	99.787%	
Chi-square (df=1)	1.00	p= .3168	
V-square (df=1)	1.00	p= .3169	
Yates corrected Chi-square	.45	p= .5045	
Phi-square	.00024		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	2091.08	p=0.0000	
Chi-square (B/C)	2097.02	p=0.0000	

x) *The frequency of cattle vs. sheep/goat pathology at svk*

H_0 There is no significant difference between the frequency of pathological cattle bones and sheep/goat bones at *svk*

H_1There is a significant difference between the frequency of pathological cattle bones and sheep/goat bones at *svk*

X^2 = .0230, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	12	1828	1840
Percent of total	.153%	23.269%	23.422%
Frequencies, row 2	78	5938	6016
Percent of total	.993%	75.586%	76.578%
Column totals	90	7766	7856
Percent of total	1.146%	98.854%	
Chi-square (df=1)	5.17	p= .023(	
V-square (df=1)	5.17	p= .023(	
Yates corrected Chi-square	4.61	p= .0317	
Phi-square	.00066		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	5900.1(	p=0.000(	
Chi-square (B/C)	1604.93	p=0.000(	

x) *The frequency of cattle vs. sheep/goat trauma at svk*

H_0 There is no significant difference between the frequency of cattle and sheep/goat *trauma* at *svk*

H_1There is a significant difference between the frequency of cattle and sheep/goat *trauma* at *svk*

X^2 = .15 *p*=.6959, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	1	1839	1840
Percent of total	.013%	23.409%	23.422%
Frequencies, row 2	5	6011	6016
Percent of total	.064%	76.515%	76.578%
Column totals	6	7850	7856
Percent of total	.076%	99.924%	
Chi-square (df=1)	.15	p= .695	
V-square (df=1)	.15	p= .695	
Yates corrected Chi-square	.01	p= .927	
Phi-square	.00002		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6006.0	p=0.000	
Chi-square (B/C)	1822.07	p=0.000	

x) *The frequency of cattle vs. sheep/goat arth at svk*

H_0 There is no significant difference between the frequency of cattle and sheep/goat *arth* at *svk*

H_1There is a significant difference between the frequency of cattle and sheep/goat arth at *svk*

$X^2 = 14.29$ p=.0002, p < 0.05, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	11	1829	1840
Percent of total	.140%	23.282%	23.422%
Frequencies, row 2	7	6009	6016
Percent of total	.089%	76.489%	76.578%
Column totals	18	7838	7856
Percent of total	.229%	99.771%	
Chi-square (df=1)	14.29	p= .0002	
V-square (df=1)	14.29	p= .0002	
Yates corrected Chi-square	12.26	p= .0005	
Phi-square	.00182		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	5974.09	p=0.000	
Chi-square (B/C)	1806.12	p=0.000	

x) *The frequency of cattle vs. sheep/goat con at svk*

H_0 There is no significant difference between the frequency of cattle and sheep/goat cong at *svk*

H_1There is a significant difference between the frequency of cattle and sheep/goat cong at *svk*

X^2 = .15 *p*=.6959, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	1	1839	1840
Percent of total	.013%	23.409%	23.422%
Frequencies, row 2	5	6011	6016
Percent of total	.064%	76.515%	76.578%
Column totals	6	7850	7856
Percent of total	.076%	99.924%	
Chi-square (df=1)	.15	p= .6959	
V-square (df=1)	.15	p= .6959	
Yates corrected Chi-square	.01	p= .9272	
Phi-square	.00002		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6006.00	p=0.0000	
Chi-square (B/C)	1822.07	p=0.0000	

x) *The frequency of cattle vs. sheep/goat nsbp at svk*

H_0 There is no significant difference between the frequency of cattle and sheep/goat *nsbp* at *svk*

H_1There is a significant difference between the frequency of cattle and sheep/goat *nsbp* at *svk*

X^2 = .16 *p*=.6852, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	1	1839	1840
Percent of total	.013%	23.409%	23.422%
Frequencies, row 2	2	6014	6016
Percent of total	.025%	76.553%	76.578%
Column totals	3	7853	7856
Percent of total	.038%	99.962%	
Chi-square (df=1)	.16	p= .6852	
V-square (df=1)	.16	p= .6852	
Yates corrected Chi-square	.08	p= .7823	
Phi-square	.00002		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6009.00	p=0.0000	
Chi-square (B/C)	1831.01	p=0.0000	

x) *The frequency of cattle vs. sheep/goat nsbl at svk*

H_0 There is no significant difference between the frequency of cattle and sheep/goat *nsbl* at *svk*

H_1 There is a significant difference between the frequency of cattle and sheep/goat *nsbl* at *svk*

$X^2 = .33$ $p=.5680$, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	1	1839	1840
Percent of total	.013%	23.409%	23.422%
Frequencies, row 2	6	6010	6016
Percent of total	.076%	76.502%	76.578%
Column totals	7	7849	7856
Percent of total	.089%	99.911%	
Chi-square (df=1)	.33	p= .5680	
V-square (df=1)	.33	p= .5680	
Yates corrected Chi-square	.02	p= .9009	
Phi-square	.00004		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6005.00	p=0.0000	
Chi-square (B/C)	1819.09	p=0.0000	

x) *The frequency of NSBP vs. NSBL for s/g at svk*

H_0 There is no significant difference between the frequency of NSBP and NSBL for s/g at *svk*

H_1There is a significant difference between the frequency of NSBP and NSBL for s/g at *svk*

X^2 =1.29 p=.2567, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	2	6014	6016
Percent of total	.017%	49.983%	50.000%
Frequencies, row 2	5	6011	6016
Percent of total	.042%	49.958%	50.000%
Column totals	7	12025	12032
Percent of total	.058%	99.942%	
Chi-square (df=1)	1.29	p= .2567	
V-square (df=1)	1.29	p= .2567	
Yates corrected Chi-square	.57	p= .4496	
Phi-square	.00011		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6003.00	p=0.0000	
Chi-square (B/C)	5997.02	p=0.0000	

Wetwang slack cattle vs. Barton Field cattle

x) *The frequency of pathological cattle at WS vs. pathological cattle at BF*

H_0 There is no significant difference between the frequency of path cattle at WS and path cattle from TH

H_1There is a significant difference between the frequency of path cattle from WS and path cattle from TH

X^2 = 2.88 p=.0895, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	48	963	1011
Percent of total	3.695%	74.134%	77.829%
Frequencies, row 2	21	267	288
Percent of total	1.617%	20.554%	22.171%
Column totals	69	1230	1299
Percent of total	5.312%	94.688%	
Chi-square (df=1)	2.88	p= .089	
V-square (df=1)	2.88	p= .089	
Yates corrected Chi-square	2.40	p= .121	
Phi-square	.00222		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	150.87	p=0.000	
Chi-square (B/C)	899.88	p=0.000	

x) *The frequency of oral pathology in cattle at WS vs oral pathology in cattle at BF*

H_0 There is no significant difference between the frequency of oral pathology in cattle from WS and cattle from TH

H_1There is a significant difference between the frequency of oral pathology in cattle from WS and cattle from TH

X^2 =.17 p=.6825, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	8	1003	1011
Percent of total	.616%	77.213%	77.829%
Frequencies, row 2	3	285	288
Percent of total	.231%	21.940%	22.171%
Column totals	11	1288	1299
Percent of total	.847%	99.153%	
Chi-square (df=1)	.17	p= .682	
V-square (df=1)	.17	p= .682	
Yates corrected Chi-square	.00	p= .964	
Phi-square	.00013		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	259.99	p=0.000	
Chi-square (B/C)	992.05	p=0.000	

x) *The frequency of arthropathy in cattle at WS vs. arthropathy in cattle at BF*

H_0 There is no significant difference between the frequency of arth in cattle from WS and cattle from TH

H_1There is a significant difference between the frequency of arth in cattle from WS and cattle from TH

X^2 =.19 p=.6613, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	14	997	1011
Percent of total	1.078%	76.751%	77.829%
Frequencies, row 2	5	283	288
Percent of total	.385%	21.786%	22.171%
Column totals	19	1280	1299
Percent of total	1.463%	98.537%	
Chi-square (df=1)	.19	p= .6613	
V-square (df=1)	.19	p= .6614	
Yates corrected Chi-square	.03	p= .8729	
Phi-square	.00015		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	241.83	p=0.0000	
Chi-square (B/C)	980.12	p=0.0000	

x) *The frequency of nsbp in cattle at WS vs. nsbp in cattle at BF*

H_0 There is no significant difference between the frequency of nsbp in cattle from WS and cattle from TH

H_1There is a significant difference between the frequency of nsbp in cattle from WS and cattle from TH

X^2 =.01 p=.9370, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	10	1001	1011
Percent of total	.770%	77.059%	77.829%
Frequencies, row 2	3	285	288
Percent of total	.231%	21.940%	22.171%
Column totals	13	1286	1299
Percent of total	1.001%	98.999%	
Chi-square (df=1)	.01	p= .937(	
V-square (df=1)	.01	p= .937(	
Yates corrected Chi-square	.07	p= .797(	
Phi-square	.00000		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	254.49	p=0.000(	
Chi-square (B/C)	990.05	p=0.000(	

x) *The frequency of nsbl in cattle at WS vs. nsbl in cattle at BF*

H_0 There is no significant difference between the frequency of nsbl in cattle from WS and cattle from TH

H_1There is a significant difference between the frequency of nsbl in cattle from WS and cattle from TH

X^2 =.77 p=.3790, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	11	1000	1011
Percent of total	.847%	76.982%	77.829%
Frequencies, row 2	5	283	288
Percent of total	.385%	21.786%	22.171%
Column totals	16	1283	1299
Percent of total	1.232%	98.768%	
Chi-square (df=1)	.77	p= .379(	
V-square (df=1)	.77	p= .379:	
Yates corrected Chi-square	.33	p= .564(	
Phi-square	.00060		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	249.80	p=0.000(	
Chi-square (B/C)	983.12	p=0.000(	

x) *The frequency of arthropathy in cattle at WS vs. arthropathy in cattle at BF*

H_0 There is no significant difference between the frequency of arth in cattle from WS and cattle from TH

H_1There is a significant difference between the frequency of arth in cattle from WS and cattle from TH

X^2 =.19 p=.6613, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

Wetwang slack s/g vs. Barton Field S/G

x) *The frequency of pathological S/G at WS vs. pathological S/G at BF*

H_0 There is no significant difference between the frequency of path S/G at WS and path S/G from TH

H_1There is a significant difference between the frequency of path S/G from WS and path S/G from TH

X^2 = 5.25 p=.0219, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	85	1917	2002
Percent of total	2.980%	67.216%	70.196%
Frequencies, row 2	21	829	850
Percent of total	.736%	29.067%	29.804%
Column totals	106	2746	2852
Percent of total	3.717%	96.283%	
Chi-square (df=1)	5.25	p= .0219	
V-square (df=1)	5.25	p= .0219	
Yates corrected Chi-square	4.77	p= .0290	
Phi-square	.00184		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	603.99	p=0.0000	
Chi-square (B/C)	1852.95	p=0.0000	

x) *The frequency of S/G oral path at WS vs. S/G oral path at BF*

H_0 There is no significant difference between the frequency of S/G oral path at WS and S/G oral path from TH

H_1There is a significant difference between the frequency of S/G oral path from WS and S/G oral path from TH

X^2 = 6.42 p=.0113, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	44	1958	2002
Percent of total	1.543%	68.654%	70.196%
Frequencies, row 2	7	843	850
Percent of total	.245%	29.558%	29.804%
Column totals	51	2801	2852
Percent of total	1.788%	98.212%	
Chi-square (df=1)	6.42	p= .0113	
V-square (df=1)	6.41	p= .0113	
Yates corrected Chi-square	5.66	p= .0174	
Phi-square	.00225		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	717.93	p=0.0000	
Chi-square (B/C)	1935.11	p=0.0000	

x) *The frequency of S/G trauma at WS vs. S/G trauma at BF*

H_0 There is no significant difference between the frequency of S/G trauma at WS and S/G trauma from TH

H_1There is a significant difference between the frequency of S/G trauma from WS and S/G trauma from TH

X^2 = 2.26 p=.1324, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	10	1992	2002
Percent of total	.351%	69.846%	70.196%
Frequencies, row 2	1	849	850
Percent of total	.035%	29.769%	29.804%
Column totals	11	2841	2852
Percent of total	.386%	99.614%	
Chi-square (df=1)	2.26	p= .1324	
V-square (df=1)	2.26	p= .1325	
Yates corrected Chi-square	1.38	p= .2402	
Phi-square	.00079		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	817.51	p=0.0000	
Chi-square (B/C)	1987.00	p=0.0000	

x) *The frequency of S/G NSBP at WS vs. S/G NSBP at BF*

H_0 There is no significant difference between the frequency of S/G NSBP at WS and S/G NSBP from TH

H_1There is a significant difference between the frequency of S/G NSBP from WS and S/G NSBP from TH

X^2 = 1.43 p=.2316, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	18	1984	2002
Percent of total	.631%	69.565%	70.196%
Frequencies, row 2	4	846	850
Percent of total	.140%	29.663%	29.804%
Column totals	22	2830	2852
Percent of total	.771%	99.229%	
Chi-square (df=1)	1.43	p= .2316	
V-square (df=1)	1.43	p= .2316	
Yates corrected Chi-square	.93	p= .3358	
Phi-square	.00050		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	791.58	p=0.0000	
Chi-square (B/C)	1970.04	p=0.0000	

x) *The frequency of S/G NSBl at WS vs. S/G NSBl at BF*

H_0 There is no significant difference between the frequency of S/G NSBl at WS and S/G NSBl from TH

H_1There is a significant difference between the frequency of S/G NSBl from WS and S/G NSBl from TH

X^2 = .04 p=.8335, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	1999	2002
Percent of total	.105%	70.091%	70.196%
Frequencies, row 2	1	849	850
Percent of total	.035%	29.769%	29.804%
Column totals	4	2848	2852
Percent of total	.140%	99.860%	
Chi-square (df=1)	.04	p= .8335	
V-square (df=1)	.04	p= .8335	
Yates corrected Chi-square	.11	p= .7363	
Phi-square	.00002		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	838.06	p=0.0000	
Chi-square (B/C)	1994.00	p=0.0000	

x) *The frequency of s/g ocm at WS vs. s/g ocm at BF*

H_0 There is no significant difference between the frequency of s/g *ocm* at WS and s/g *ocm* from BF

H_1There is a significant difference between the frequency of path s/g *ocm* from WS and s/g *ocm* fromBF

X^2 = 4.38p=.0365, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	8	1994	2002
Percent of total	.281%	69.916%	70.196%
Frequencies, row 2	9	841	850
Percent of total	.316%	29.488%	29.804%
Column totals	17	2835	2852
Percent of total	.596%	99.404%	
Chi-square (df=1)	4.38	p= .0365	
V-square (df=1)	4.37	p= .0365	
Yates corrected Chi-square	3.33	p= .0679	
Phi-square	.00153		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	815.34	p=0.0000	
Chi-square (B/C)	1965.18	p=0.0000	

x) *The frequency of cattle ocm at WS vs. cattle ocm at BF*

H_0 There is no significant difference between the frequency of *cattle ocm* at WS and *cattle ocm* from BF

H_1There is a significant difference between the frequency of path *cattle ocm* from WS and *cattle ocm* fromBF

X^2 = .92 p=.3363, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	1008	1011
Percent of total	.231%	77.598%	77.829%
Frequencies, row 2	2	286	288
Percent of total	.154%	22.017%	22.171%
Column totals	5	1294	1299
Percent of total	.385%	99.615%	
Chi-square (df=1)	.92	p= .3363	
V-square (df=1)	.92	p= .3364	
Yates corrected Chi-square	.18	p= .6728	
Phi-square	.00071		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	275.17	p=0.0000	
Chi-square (B/C)	1000.02	p=0.0000	

hof cattle vs. svk cattle

x) *The frequency of pathological cattle at WS vs. pathological cattle at BF*

H_0 There is no significant difference between the frequency of path cattle at WS and path cattle from TH

H_1There is a significant difference between the frequency of path cattle from WS and path cattle from TH

X^2 = 16.52 p=.0000, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	47	2067	2114
Percent of total	1.189%	52.276%	53.465%
Frequencies, row 2	12	1828	1840
Percent of total	.303%	46.232%	46.535%
Column totals	59	3895	3954
Percent of total	1.492%	98.508%	
Chi-square (df=1)	16.52	p= .0000	
V-square (df=1)	16.52	p= .0000	
Yates corrected Chi-square	15.47	p= .0001	
Phi-square	.00418		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1689.81	p=0.0000	
Chi-square (B/C)	2029.30	p=0.0000	

x) *The frequency of cattle oral path at hst vs. cattle oral path at svk*

H_0 There is no significant difference between the frequency of cattle *oral path* at hst and cattle *oral path* from svk

H_1There is a significant difference between the frequency of path cattle *oral path* from hst and cattle *oral path* from svk

X^2 = .75 p=.3876, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	2111	2114
Percent of total	.076%	53.389%	53.465%
Frequencies, row 2	1	1839	1840
Percent of total	.025%	46.510%	46.535%
Column totals	4	3950	3954
Percent of total	.101%	99.899%	
Chi-square (df=1)	.75	p= .3876	
V-square (df=1)	.75	p= .3877	
Yates corrected Chi-square	.13	p= .7170	
Phi-square	.00019		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1828.03	p=0.0000	
Chi-square (B/C)	2106.00	p=0.0000	

x) *The frequency of cattle arth at hst vs. cattle arth at svk*

H_0 There is no significant difference between the frequency of cattle *arth* at hst and cattle *arth* from svk

H_1 There is a significant difference between the frequency of path cattle *arth* from hst and cattle *arth* from svk

$X^2 = 10.23$ p=.0014, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	36	2078	2114
Percent of total	.910%	52.554%	53.465%
Frequencies, row 2	11	1829	1840
Percent of total	.278%	46.257%	46.535%
Column totals	47	3907	3954
Percent of total	1.189%	98.811%	
Chi-square (df=1)	10.23	p= .0014	
V-square (df=1)	10.23	p= .0014	
Yates corrected Chi-square	9.31	p= .0023	
Phi-square	.00259		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1721.86	p=0.0000	
Chi-square (B/C)	2043.25	p=0.0000	

x) *The frequency of cattle cong at hst vs. cattle cong at svk*

H_0 There is no significant difference between the frequency of cattle *cong* at hst and cattle *cong* from svk

H_1There is a significant difference between the frequency of path cattle *cong* from hst and cattle *cong* from svk

X^2 = 1.42 p=.2339, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	4	2110	2114
Percent of total	.101%	53.364%	53.465%
Frequencies, row 2	1	1839	1840
Percent of total	.025%	46.510%	46.535%
Column totals	5	3949	3954
Percent of total	.126%	99.874%	
Chi-square (df=1)	1.42	p= .2339	
V-square (df=1)	1.42	p= .2340	
Yates corrected Chi-square	.55	p= .4583	
Phi-square	.00036		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1825.04	p=0.0000	
Chi-square (B/C)	2105.00	p=0.0000	

x) *The frequency of cattle nsbp at hst vs. cattle nsbp at svk*

H_0 There is no significant difference between the frequency of cattle *nsbp* at hst and cattle *nsbp* from svk

H_1There is a significant difference between the frequency of path cattle *nsbp* from hst and cattle *nsbp* from svk

X^2 = 2.93 p=.0869, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	6	2108	2114
Percent of total	.152%	53.313%	53.465%
Frequencies, row 2	1	1839	1840
Percent of total	.025%	46.510%	46.535%
Column totals	7	3947	3954
Percent of total	.177%	99.823%	
Chi-square (df=1)	2.93	p= .086	
V-square (df=1)	2.93	p= .086	
Yates corrected Chi-square	1.78	p= .182	
Phi-square	.00074		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1819.0	p=0.000	
Chi-square (B/C)	2103.0	p=0.000	

x) *The frequency of cattle nsbl at hst vs. cattle nsbl at svk*

H_0 There is no significant difference between the frequency of cattle *nsbl* at hst and cattle *nsbl* from svk

H_1There is a significant difference between the frequency of path cattle *nsbl* from hst and cattle *nsbl* from svk

X^2 = .75 p=.3876, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	2111	2114
Percent of total	.076%	53.389%	53.465%
Frequencies, row 2	1	1839	1840
Percent of total	.025%	46.510%	46.535%
Column totals	4	3950	3954
Percent of total	.101%	99.899%	
Chi-square (df=1)	.75	p= .387	
V-square (df=1)	.75	p= .387	
Yates corrected Chi-square	.13	p= .717	
Phi-square	.00019		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	1828.03	p=0.000	
Chi-square (B/C)	2106.0	p=0.000	

Sheep vs. sheep

x) *The frequency of s/g path at hst vs. s/g path at svk*

H_0 There is no significant difference between the frequency of s/g *path* at hst and s/g *path* from svk

H_1There is a significant difference between the frequency of s/g *path* from hst and s/g *path* from svk

X^2 = 11.57 p=.0007, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	134	6288	6422
Percent of total	1.077%	50.555%	51.632%
Frequencies, row 2	78	5938	6016
Percent of total	.627%	47.741%	48.368%
Column totals	212	12226	12438
Percent of total	1.704%	98.296%	
Chi-square (df=1)	11.57	p= .0007	
V-square (df=1)	11.57	p= .0007	
Yates corrected Chi-square	11.11	p= .0009	
Phi-square	.00093		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	5545.92	p=0.0000	
Chi-square (B/C)	6055.87	p=0.0000	

x) *The frequency of s/g oral path at hst vs. s/g oral path at svk*

H_0 There is no significant difference between the frequency of s/g *oral path* at hst and s/g *oral path* from svk

H_1There is a significant difference between the frequency of path s/g *oral path* from hst and s/g *oral path* from svk

X^2 = 19.79 p=.0000, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	96	6326	6422
Percent of total	.772%	50.860%	51.632%
Frequencies, row 2	40	5976	6016
Percent of total	.322%	48.046%	48.368%
Column totals	136	12302	12438
Percent of total	1.093%	98.907%	
Chi-square (df=1)	19.79	p= .0000	
V-square (df=1)	19.78	p= .0000	
Yates corrected Chi-square	19.03	p= .0000	
Phi-square	.00159		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	5692.13	p=0.0000	
Chi-square (B/C)	6205.03	p=0.0000	

x) *The frequency of s/g trauma at hst vs. s/g trauma at svk*

H_0 There is no significant difference between the frequency of s/g *trauma* at hst and s/g *trauma* from svk

H_1There is a significant difference between the frequency of path s/g *trauma* from hst and s/g *trauma* from svk

X^2 = .51 p=.4745, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	8	6414	6422
Percent of total	.064%	51.568%	51.632%
Frequencies, row 2	5	6011	6016
Percent of total	.040%	48.328%	48.368%
Column totals	13	12425	12438
Percent of total	.105%	99.895%	
Chi-square (df=1)	.51	p= .4745	
V-square (df=1)	.51	p= .4746	
Yates corrected Chi-square	.19	p= .6618	
Phi-square	.00004		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	5985.05	p=0.0000	
Chi-square (B/C)	6397.02	p=0.0000	

x) *The frequency of s/g arth at hst vs. s/g arth at svk*

H_0 There is no significant difference between the frequency of s/g *arth* at hst and s/g *arth* from svk

H_1There is a significant difference between the frequency of path s/g *arth* from hst and s/g *arth* from svk

X^2 = 4.91 p=.0267, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	1	6421	6422
Percent of total	.008%	51.624%	51.632%
Frequencies, row 2	7	6009	6016
Percent of total	.056%	48.312%	48.368%
Column totals	8	12430	12438
Percent of total	.064%	99.936%	
Chi-square (df=1)	4.91	p= .0267	
V-square (df=1)	4.91	p= .0267	
Yates corrected Chi-square	3.47	p= .0627	
Phi-square	.00039		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6004.00	p=0.0000	
Chi-square (B/C)	6398.03	p=0.0000	

x) *The frequency of s/cong at hst vs. s/g cong at svk*

H_0 There is no significant difference between the frequency of s/g *cong* at hst and s/g *cong* from svk

H_1There is a significant difference between the frequency of path s/g *cong* from hst and s/g *cong* from svk

X^2 = 1.49 p=.2220, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	2	6420	6422
Percent of total	.016%	51.616%	51.632%
Frequencies, row 2	5	6011	6016
Percent of total	.040%	48.328%	48.368%
Column totals	7	12431	12438
Percent of total	.056%	99.944%	
Chi-square (df=1)	1.49	p= .222(	
V-square (df=1)	1.49	p= .222(	
Yates corrected Chi-square	.71	p= .399:	
Phi-square	.00012		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	6003.0(	p=0.000(	
Chi-square (B/C)	6403.0:	p=0.000(	

x) *The frequency of s/g nsbp at hst vs. s/g nsbp at svk*

H_0 There is no significant difference between the frequency of s/g *nsbp* at hst and s/g *nsbp* from svk

H_1There is a significant difference between the frequency of path s/g *nsbp* from hst and s/g *nsbp* from svk

X^2 = 10.91 p=.0010, p < 0.05, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	17	6405	6422
Percent of total	.137%	51.495%	51.632%
Frequencies, row 2	2	6014	6016
Percent of total	.016%	48.352%	48.368%
Column totals	19	12419	12438
Percent of total	.153%	99.847%	
Chi-square (df=1)	10.91	p= .001(	
V-square (df=1)	10.91	p= .001(	
Yates corrected Chi-square	9.45	p= .002:	
Phi-square	.00088		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	5961.2(	p=0.000(	
Chi-square (B/C)	6397.0(	p=0.000(	

x) *The frequency of s/g nsbl at hst vs. s/g nsbl at svk*

H_0 There is no significant difference between the frequency of s/g *nsbl* at hst and s/g *nsbl* from svk

H_1There is a significant difference between the frequency of path s/g *nsbl* from hst and s/g *nsbl* from svk

X^2 = .17 p=.6797, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	8	6414	6422
Percent of total	.064%	51.568%	51.632%
Frequencies, row 2	6	6010	6016
Percent of total	.048%	48.320%	48.368%
Column totals	14	12424	12438
Percent of total	.113%	99.887%	
Chi-square (df=1)	.17	p= .6797	
V-square (df=1)	.17	p= .6797	
Yates corrected Chi-square	.02	p= .8845	
Phi-square	.00001		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	5984.05	p=0.0000	
Chi-square (B/C)	6394.03	p=0.0000	

x) *The frequency of s/g ocm at hst vs. s/g ocm at svk*

H_0 There is no significant difference between the frequency of s/g *ocm* at hst and s/g *ocm* from svk

H_1There is a significant difference between the frequency of path s/g *ocm* from hst and s/g *ocm* from svk

X^2 = 11.24 p=.0008, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	16	6406	6422
Percent of total	.129%	51.503%	51.632%
Frequencies, row 2	39	5977	6016
Percent of total	.314%	48.054%	48.368%
Column totals	55	12383	12438
Percent of total	.442%	99.558%	
Chi-square (df=1)	11.24	p= .0008	
V-square (df=1)	11.24	p= .0008	
Yates corrected Chi-square	10.35	p= .0013	
Phi-square	.00090		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	5927.18	p=0.0000	
Chi-square (B/C)	6287.97	p=0.0000	

Cattle: IA vs VA Aetiologies (ww, BF & hst, svk)

x) *The frequency of cattle path at IA sites vs. cattle path at VA sites*

H_0 There is no significant difference between the frequency of cattle *path* at IA sites and cattle *path at VA sites*

H_1There is a significant difference between the frequency of cattle *path* at IA sites and cattle *path at VA sites*

X^2 = 60.01 p=.0000, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	69	1230	1299
Percent of total	1.314%	23.415%	24.729%
Frequencies, row 2	59	3895	3954
Percent of total	1.123%	74.148%	75.271%
Column totals	128	5125	5253
Percent of total	2.437%	97.563%	
Chi-square (df=1)	60.01	p= .0000	
V-square (df=1)	59.99	p= .0000	
Yates corrected Chi-square	58.41	p= .0000	
Phi-square	.01142		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	3690.87	p=0.0000	
Chi-square (B/C)	1061.99	p=0.0000	

x) *The frequency of cattle trauma at IA sites vs. cattle trauma at VA sites*

H_0 There is no significant difference between the frequency of cattle *trauma* at IA sites and cattle *trauma at VA sites*

H_1 There is a significant difference between the frequency of cattle *trauma* at IA sites and cattle *trauma at VA sites*

$X^2 = .24$ p=.6250, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	2	1297	1299
Percent of total	.038%	24.691%	24.729%
Frequencies, row 2	4	3950	3954
Percent of total	.076%	75.195%	75.271%
Column totals	6	5247	5253
Percent of total	.114%	99.886%	
Chi-square (df=1)	.24	p= .6250	
V-square (df=1)	.24	p= .6250	
Yates corrected Chi-square	.00	p= .9877	
Phi-square	.00005		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	3942.01	p=0.0000	
Chi-square (B/C)	1283.06	p=0.0000	

x) *The frequency of cattle arth at IA sites vs. cattle arth at VA sites*

H_0 There is no significant difference between the frequency of cattle *arth* at IA sites and cattle *arth at VA sites*

H_1There is a significant difference between the frequency of cattle *arth* at IA sites and cattle *arth at VA sites*

X^2 = .59 p=.4418, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	19	1280	1299
Percent of total	.362%	24.367%	24.729%
Frequencies, row 2	47	3907	3954
Percent of total	.895%	74.377%	75.271%
Column totals	66	5187	5253
Percent of total	1.256%	98.744%	
Chi-square (df=1)	.59	p= .4418	
V-square (df=1)	.59	p= .4418	
Yates corrected Chi-square	.39	p= .5316	
Phi-square	.00011		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	3848.39	p=0.0000	
Chi-square (B/C)	1143.80	p=0.0000	

x) *The frequency of cattle cong at IA sites vs. cattle cong at VA sites*

H_0 There is no significant difference between the frequency of cattle cong at IA sites and cattle cong *at VA sites*

H_1There is a significant difference between the frequency of cattle *cong* at IA sites and cattle *cong at VA sites*

X^2 = 5.26 p=.0218, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	6	1293	1299
Percent of total	.114%	24.615%	24.729%
Frequencies, row 2	5	3949	3954
Percent of total	.095%	75.176%	75.271%
Column totals	11	5242	5253
Percent of total	.209%	99.791%	
Chi-square (df=1)	5.26	p= .0218	
V-square (df=1)	5.26	p= .0218	
Yates corrected Chi-square	3.78	p= .0518	
Phi-square	.00100		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	3929.04	p=0.0000	
Chi-square (B/C)	1276.09	p=0.0000	

x) *The frequency of cattle nsbp at IA sites vs. cattle nsbp at VA sites*

H_0 There is no significant difference between the frequency of cattle *nsbp* at IA sites and cattle *nsbp at VA sites*

H_1There is a significant difference between the frequency of cattle *nsbp* at IA sites and cattle *nsbp at VA sites*

X^2 = 15.71 p=.0001, p < 0.05, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	13	1386	1399
Percent of total	.243%	25.892%	26.135%
Frequencies, row 2	7	3947	3954
Percent of total	.131%	73.734%	73.865%
Column totals	20	5333	5353
Percent of total	.374%	99.626%	
Chi-square (df=1)	15.71	p= .0001	
V-square (df=1)	15.70	p= .0001	
Yates corrected Chi-square	13.75	p= .0002	
Phi-square	.00293		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	3906.18	p=0.0000	
Chi-square (B/C)	1363.16	p=0.0000	

x) *The frequency of cattle nsbl at IA sites vs. cattle nsbl at VA sites*

H_0 There is no significant difference between the frequency of cattle *nsbl* at IA sites and cattle *nsbl at VA sites*

H_1There is a significant difference between the frequency of cattle *nsbl* at IA sites and cattle *nsbl at VA sites*

X^2 = 32.95 p=.0000, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	16	1283	1299
Percent of total	.305%	24.424%	24.729%
Frequencies, row 2	4	3950	3954
Percent of total	.076%	75.195%	75.271%
Column totals	20	5233	5253
Percent of total	.381%	99.619%	
Chi-square (df=1)	32.95	p= .0000	
V-square (df=1)	32.94	p= .0000	
Yates corrected Chi-square	30.04	p= .0000	
Phi-square	.00627		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	3900.27	p=0.0000	
Chi-square (B/C)	1269.06	p=0.0000	

x) *The frequency of cattle ocm at IA sites vs. cattle ocm at VA sites*

H_0 There is no significant difference between the frequency of cattle *ocm* at IA sites and cattle *ocm at VA sites*

H_1There is a significant difference between the frequency of cattle *ocm* at IA sites and cattle *ocm at VA sites*

X^2 = 6.15 p=.0131, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	5	1293	1298
Percent of total	.095%	24.610%	24.705%
Frequencies, row 2	3	3953	3956
Percent of total	.057%	75.238%	75.295%
Column totals	8	5246	5254
Percent of total	.152%	99.848%	
Chi-square (df=1)	6.15	p= .0131	
V-square (df=1)	6.15	p= .0131	
Yates corrected Chi-square	4.29	p= .0384	
Phi-square	.00117		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	3936.03	p=0.0000	
Chi-square (B/C)	1282.04	p=0.0000	

IA vs VA sheep/goat (ww, bf & hft and svg)

x) *The frequency of IA S/G PATH vs. VA S/G PATH*

H_0 There is no significant difference between the frequency of IA S/G *PATH* and VA S/G *PATH*

H_1 There is a significant difference between the frequency of IA S/G *PATH* and VA S/G *PATH*

$X^2 = 46.13$ p=.0000, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	106	2746	2852
Percent of total	.693%	17.959%	18.653%
Frequencies, row 2	212	12226	12438
Percent of total	1.387%	79.961%	81.347%
Column totals	318	14972	15290
Percent of total	2.080%	97.920%	
Chi-square (df=1)	46.13	p= .0000	
V-square (df=1)	46.12	p= .0000	
Yates corrected Chi-square	45.14	p= .0000	
Phi-square	.00302		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	11909.7	p=0.0000	
Chi-square (B/C)	2169.06	p=0.0000	

x) *The frequency of IA S/G oral path vs. VA S/G oral path*

H_0 There is no significant difference between the frequency of IA S/G oral path and VA S/G oral path

H_1There is a significant difference between the frequency of IA S/G oral path and VA S/G oral path

X^2 = 9.27 p=.0023, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	51	2801	2852
Percent of total	.334%	18.319%	18.653%
Frequencies, row 2	136	12302	12438
Percent of total	.889%	80.458%	81.347%
Column totals	187	15103	15290
Percent of total	1.223%	98.777%	
Chi-square (df=1)	9.27	p= .0023	
V-square (df=1)	9.27	p= .0023	
Yates corrected Chi-square	8.70	p= .0032	
Phi-square	.00061		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12147.9	p=0.0000	
Chi-square (B/C)	2416.38	p=0.0000	

x) *The frequency of IA S/G trauma vs. VA S/G trauma*

H_0 There is no significant difference between the frequency of IA S/G trauma and VA S/G trauma

H_1There is a significant difference between the frequency of IA S/G trauma and VA S/G trauma

X^2 = 11.70p=.0006, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	11	2841	2852
Percent of total	.072%	18.581%	18.653%
Frequencies, row 2	13	12425	12438
Percent of total	.085%	81.262%	81.347%
Column totals	24	15266	15290
Percent of total	.157%	99.843%	
Chi-square (df=1)	11.70	p= .0006	
V-square (df=1)	11.70	p= .0006	
Yates corrected Chi-square	9.98	p= .0016	
Phi-square	.00077		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12390.0	p=0.0000	
Chi-square (B/C)	2800.26	p=0.0000	

x) *The frequency of IA S/G arth vs. VA S/G arth*

H_0 There is no significant difference between the frequency of IA S/G *arth* and VA S/G *arth*

H_1 There is a significant difference between the frequency of IA S/G *arth* and VA S/G *arth*

X^2 = .54 p=.4628, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	2849	2852
Percent of total	.020%	18.633%	18.653%
Frequencies, row 2	8	12430	12438
Percent of total	.052%	81.295%	81.347%
Column totals	11	15279	15290
Percent of total	.072%	99.928%	
Chi-square (df=1)	.54	p= .4628	
V-square (df=1)	.54	p= .4628	
Yates corrected Chi-square	.12	p= .7286	
Phi-square	.00004		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12419.0	p=0.0000	
Chi-square (B/C)	2823.10	p=0.0000	

x) *The frequency of IA S/G cong vs. VA S/G cong*

H_0 There is no significant difference between the frequency of IA S/G *cong* and VA S/G *cong*

H_1 There is a significant difference between the frequency of IA S/G *cong* and VA S/G *cong*

X^2 = .08 p=.7833, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	2	2850	2852
Percent of total	.013%	18.640%	18.653%
Frequencies, row 2	7	12431	12438
Percent of total	.046%	81.302%	81.347%
Column totals	9	15281	15290
Percent of total	.059%	99.941%	
Chi-square (df=1)	.08	p= .7833	
V-square (df=1)	.08	p= .7833	
Yates corrected Chi-square	.02	p= .8784	
Phi-square	.00000		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12423.0	p=0.0000	
Chi-square (B/C)	2827.08	p=0.0000	

x) *The frequency of IA S/G nsbp vs. VA S/G nsbp*

H_0 There is no significant difference between the frequency of IA S/G *nsbp* and VA S/G *nsbp*

H_1 There is a significant difference between the frequency of IA S/G *nsbp* and VA S/G *nsbp*

X^2 = 33.20 p=.0000, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	22	2830	2852
Percent of total	.144%	18.509%	18.653%
Frequencies, row 2	19	12419	12438
Percent of total	.124%	81.223%	81.347%
Column totals	41	15249	15290
Percent of total	.268%	99.732%	
Chi-square (df=1)	33.20	p= .0000	
V-square (df=1)	33.20	p= .0000	
Yates corrected Chi-square	30.93	p= .0000	
Phi-square	.00217		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12351.2	p=0.0000	
Chi-square (B/C)	2771.53	p=0.0000	

x) *The frequency of IA S/G nsbl vs. VA S/G nsbl*

H_0 There is no significant difference between the frequency of IA S/G *nsbl* and VA S/G *nsbl*

H_1 There is a significant difference between the frequency of IA S/G *nsbl* and VA S/G *nsbl*

$X^2 = .15$ p=.6973, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	4	2848	2852
Percent of total	.026%	18.627%	18.653%
Frequencies, row 2	14	12424	12438
Percent of total	.092%	81.256%	81.347%
Column totals	18	15272	15290
Percent of total	.118%	99.882%	
Chi-square (df=1)	.15	p= .6973	
V-square (df=1)	.15	p= .6973	
Yates corrected Chi-square	.01	p= .9312	
Phi-square	.00001		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12410.0	p=0.0000	
Chi-square (B/C)	2804.29	p=0.0000	

x) *The frequency of IA S/G OCM vs. VA S/G OCM*

H_0 There is no significant difference between the frequency of IA S/G *OCM* and VA S/G *OCM*

H_1There is a significant difference between the frequency of IA S/G *OCM* and VA S/G *OCM*

X^2 = .36 p=.5501, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	15	2837	2852
Percent of total	.098%	18.555%	18.653%
Frequencies, row 2	55	12383	12438
Percent of total	.360%	80.988%	81.347%
Column totals	70	15220	15290
Percent of total	.458%	99.542%	
Chi-square (df=1)	.36	p= .5501	
V-square (df=1)	.36	p= .5501	
Yates corrected Chi-square	.20	p= .6572	
Phi-square	.00002		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12336.1	p=0.0000	
Chi-square (B/C)	2674.26	p=0.0000	

Non-specific bone proliferation distribution by site (all species)

x) *The distribution of NSBP distribution*

H_0 There is no significant difference in the skeletal distribution of NSBP at Wetwang Slack (allphases)

H_1There is a significant difference in the skeletal distribution of NSBP at Wetwang Slack

X^2 = 23.76 p=.0000, p < 0.05, d.f. = 2

H_0 is rejected at α = 0.05

Case	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 23.76000 df = 3 p = .000028 observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	15.0000(	12.5000(	2.500(	0.5000(
C: 2	11.0000(	12.5000(	-1.500(	0.1800(
C: 3	24.0000(	12.5000(	11.500(	10.5800(
C: 4	0.0000(	12.5000(	-12.500(	12.5000(
Sum	50.0000(	50.0000(	0.000(	23.7600(

x) *The distribution of NSBP distribution*

H_0 There is no significant difference in the distribution of NSBP by axial region and by appendicular region at Wetwang Slack (all phases)

H_1There is a significant difference in the distribution of NSBP by axial region and by appendicular region at Wetwang Slack at Wetwang Slack

$X^2 = 4.82$ p=.0279, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

Case	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 4.828571 df = 1 p = .027993 observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	11.0000(	17.5000(	-6.5000(	2.414286
C: 2	24.0000(	17.5000(	6.5000(	2.414286
Sum	35.0000(	35.0000(	0.0000(	4.828571

H_0 There is no significant difference in the distribution of NSBP by axial region and by appendicular region at Wetwang Slack (IA)

H_1There is a significant difference in the distribution of NSBP by axial region and by appendicular region at Wetwang Slack at Wetwang Slack

$X^2 = 4.48$ p=.0342, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 4.481481 df = 1 p = .034265			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	19.0000(	13.5000(	5.5000(	2.24074
C: 2	8.0000(	13.5000(	-5.5000(	2.24074
Sum	27.0000(	27.0000(	0.0000(	4.48148

x) *The distribution of NSBP distribution*

H_0 There is no significant difference in the skeletal distribution of NSBP at Wetwang Slack (IA)

H_1There is a significant difference in the skeletal distribution of NSBP at Wetwang Slack

X^2 = 19.40 p=.0002, p < 0.05, d.f. = 3

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 19.40000 df = 3 p = .000226			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	0.0000(	10.0000(	-10.000(	10.0000(
C: 2	13.0000(	10.0000(	3.000(	0.9000(
C: 3	8.0000(	10.0000(	-2.000(	0.4000(
C: 4	19.0000(	10.0000(	9.000(	8.1000(
Sum	40.0000(	40.0000(	0.000(	19.4000(

x) *The distribution of NSBP distribution*

H_0 There is no significant difference in the skeletal distribution of NSBP by axial region and by appendicular region at Barton Field, Tarrant Hinton

H_1There is a significant difference in the skeletal distribution of NSBP by axial region and by appendicular region at Barton Field, Tarrant Hinton

X^2 = 5.33 p=.0209, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 5.333333 df = 1 p = .020922			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	2.00000(	6.00000(	-4.00000(	2.666667
C: 2	10.0000(	6.00000(	4.00000(	2.666667
Sum	12.0000(	12.0000(	0.00000(	5.333333

x) *The distribution of NSBP distribution*

H_0 There is no significant difference in the skeletal distribution of NSBP at Hofstadir

H_1There is a significant difference in the skeletal distribution of NSBP at Hofstadir

X^2 = 24.15 p=.0000, p < 0.05, d.f. = 3

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 24.15385 df = 3 p = .000023			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	0.00000(	6.50000(	-6.50000(	6.50000(
C: 2	15.0000(	6.50000(	8.50000(	11.11538
C: 3	1.00000(	6.50000(	-5.50000(	4.65385
C: 4	10.0000(	6.50000(	3.50000(	1.88462
Sum	26.0000(	26.0000(	0.00000(	24.15385

x) *The distribution of NSBP distribution*

H_0 There is no significant difference in the distribution of NSBP by axial region and by appendicular region at hofstadir

H_1There is a significant difference in the distribution of NSBP by axial region and by appendicular region at hofstadir

X^2 = 7.36 p=.0066, p < 0.05, d.f. = 3

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 7.363636 df = 1 p = .006656			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	1.0000(	5.5000(	-4.5000(	3.681818
C: 2	10.0000(	5.5000(	4.5000(	3.681818
Sum	11.0000(	11.0000(	0.0000(	7.363636

x) *The distribution of NSBl distribution*

H_0 There is no significant difference in the skeletal distribution of NSBL by axial region and by appendicular region at Wetwang Slack

H_1There is a significant difference in the skeletal distribution of NSBL by axial region and by appendicular region at Wetwang Slack

X^2 = 1.47 p=.2252, p < 0.05, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 1.470588 df = 1 p = .225254			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	11.0000(	8.5000(	2.5000(	0.735294
C: 2	6.0000(	8.5000(	-2.5000(	0.735294
Sum	17.0000(	17.0000(	0.0000(	1.470588

x) *The distribution of NSBl distribution*

H_0 There is no significant difference in the skeletal distribution of NSBL by axial region and by appendicular region at Wetwang Slack (IA)

H_1There is a significant difference in the skeletal distribution of NSBL by axial region and by appendicular region at Wetwang Slack

X^2 = 3.26 p=.0707, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 3.266667 df = 1 p = .070702			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	11.0000(	7.5000(	3.5000(	1.633333
C: 2	4.0000(	7.5000(	-3.5000(	1.633333
Sum	15.0000(	15.0000(	0.0000(	3.266667

x) *The distribution of NSBl distribution*

H_0 There is no significant difference in the skeletal distribution of NSBL at Wetwang Slack(all phases)

H_1There is a significant difference in the skeletal distribution of NSBL at Wetwang Slack

X^2 = 11.95 p=.0075, p < 0.05, d.f. = 3

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 11.95238 df = 3 p = .007549			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	4.0000(	5.2500(	-1.2500(	0.29762
C: 2	0.0000(	5.2500(	-5.2500(	5.2500(
C: 3	11.0000(	5.2500(	5.7500(	6.29762
C: 4	6.0000(	5.2500(	0.7500(	0.10714
Sum	21.0000(	21.0000(	0.0000(	11.95238

x) *The distribution of NSBl distribution*

H_0 There is no significant difference in the skeletal distribution of NSBL by axial region and by appendicular region at Barton Field, Tarrant Hinton

H_1There is a significant difference in the skeletal distribution of NSBL by axial region and by appendicular region at Barton Field, Tarrant Hinton

X^2 = 4.45 p=.0348, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadsheet Chi-Square = 4.454545 df = 1 p = .034809			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	9.0000(	5.5000(	3.5000(	2.227273
C: 2	2.0000(	5.5000(	-3.5000(	2.227273
Sum	11.0000(	11.0000(	0.0000(	4.454545

x) *The distribution of NSBl distribution*

H_0 There is no significant difference in the distribution of NSBl by axial region and by appendicular region at Westness

H_1There is a significant difference in the distribution of NSBl by axial region and by appendicular region at Westness

X^2 = 13.00 p=.0003, p < 0.05, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 13.00000 df = 1 p = .000312			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	13.0000(	6.5000(	6.5000(	6.5000(
C: 2	0.0000(	6.5000(	-6.5000(	6.5000(
Sum	13.0000(	13.0000(	0.0000(	13.0000(

x) *The distribution of NSBl distribution*

H_0 There is no significant difference in the distribution of NSBl by axial region and by appendicular region at hofstadir

H_1There is a significant difference in the distribution of NSBl by axial region and by appendicular region at hofstadir

X^2 = .818 p=.3657, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	Observed vs. Expected Frequencies (Spreadsheet Chi-Square = .8181818 df = 1 p = .365713			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	7.0000(	5.5000(	1.5000(	0.409091
C: 2	4.0000(	5.5000(	-1.5000(	0.409091
Sum	11.0000(	11.0000(	0.0000(	0.818182

x) *The distribution of NSBl distribution*

H_0 There is no significant difference in the distribution of NSBl by axial region and by appendicular region at sveigakot

H_1There is a significant difference in the distribution of NSBl by axial region and by appendicular region at sveigakot

X^2 = 3.60 p=.0577, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	Observed vs. Expected Frequencies (Spreadsheet Chi-Square = 3.600000 df = 1 p = .057780			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	8.0000(	5.0000(	3.0000(	1.80000(
C: 2	2.0000(	5.0000(	-3.0000(	1.80000(
Sum	10.0000(	10.0000(	0.0000(	3.60000(

x) *The distribution of pathological lesions in Wetwang Slack cattle ABGs*

H_0 There is no significant difference in the skeletal distribution of pathological lesions in cattle ABGs at Wetwang Slack

H_1There is a significant difference in the skeletal distribution of pathological lesions in cattle ABGs at Wetwang Slack

X^2 = 43.25 p=.0000, p < 0.05, d.f. = 3

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 43.25714 df = 3 p = .000000			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	5.0000(	17.5000(	-12.500(	8.92857
C: 2	6.0000(	17.5000(	-11.500(	7.55714
C: 3	39.0000(	17.5000(	21.500(	26.41429
C: 4	20.0000(	17.5000(	2.500(	0.35714
Sum	70.0000(	70.0000(	0.000(	43.25714

x) *The distribution of pathological lesions in Wetwang Slack s/g ABGs*

H_0 There is no significant difference in the skeletal distribution of pathological lesions in s/g ABGs at Wetwang Slack

H_1There is a significant difference in the skeletal distribution of pathological lesions in s/g ABGs at Wetwang Slack

X^2 = 17.29 p=.0006, p < 0.05, d.f. = 3

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 17.29630 df = 3 p = .000614			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	0.0000(	6.7500(	-6.7500(	6.7500(
C: 2	3.0000(	6.7500(	-3.7500(	2.08333
C: 3	13.0000(	6.7500(	6.2500(	5.78704
C: 4	11.0000(	6.7500(	4.2500(	2.67593
Sum	27.0000(	27.0000(	0.0000(	17.2963(

x) *The distribution of pathological lesions in Wetwang Slack PIGS ABGs*

H_0 There is no significant difference in the skeletal distribution of pathological lesions in PIGS ABGs at Wetwang Slack

H_1There is a significant difference in the skeletal distribution of pathological lesions in PIGS ABGs at Wetwang Slack

X^2 = .09 p=.7630, p > 0.05, d.f. = 1

H_0 is ACCEPTED at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = .0909091 df = 1 p = .763025			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	5.0000(	5.5000(	-0.50000(	0.04545
C: 2	6.0000(	5.5000(	0.50000(	0.04545
Sum	11.0000(	11.0000(	0.00000(	0.09090

x) *The distribution of pathological lesions in Wetwang Slack horse ABGs*

H_0 There is no significant difference in the skeletal distribution of pathological lesions in horse ABGs at Wetwang Slack

H_1There is a significant difference in the skeletal distribution of pathological lesions in horse ABGs at Wetwang Slack

X^2 = 8.32 p=.0039, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 8.320755 df = 1 p = .003920			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	37.0000(	26.5000(	10.500(	4.160377
C: 2	16.0000(	26.5000(	-10.500(	4.160377
Sum	53.0000(	53.0000(	0.000(	8.320755

x) *The distribution of pathological lesions in Danebury Hillfort cattle ABGs*

H_0 There is no significant difference in the skeletal distribution of pathological lesions in *cattle* ABGs at Danebury hillfort

H_1There is a significant difference in the skeletal distribution of pathological lesions in *cattle* ABGs at Danebury hillfort

X^2 = 50.0 p=.0000, p < 0.05, d.f. = 3

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 50.00000 df = 3 p = .000000			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	1.0000(	8.5000(	-7.5000(	6.61765
C: 2	1.0000(	8.5000(	-7.5000(	6.61765
C: 3	26.0000(	8.5000(	17.5000(	36.02941
C: 4	6.0000(	8.5000(	-2.5000(	0.73529
Sum	34.0000(	34.0000(	0.0000(	50.0000(

x) *The distribution of pathological lesions in Danebury Hillfort s/g ABGs*

H_0 There is no significant difference in the skeletal distribution of pathological lesions in s/g abgs at Danebury hillfort

H_1There is a significant difference in the skeletal distribution of pathological lesions in s/g abgs at Danebury hillfort

X^2 = 11.95 p=.0075, p < 0.05, d.f. = 3

H_0 is rejected at α = 0.05

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 11.95238 df = 3 p = .007549			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	0.00000	5.25000	-5.25000	5.25000
C: 2	6.00000	5.25000	0.75000	0.10714
C: 3	11.00000	5.25000	5.75000	6.29762
C: 4	4.00000	5.25000	-1.25000	0.29762
Sum	21.00000	21.00000	0.00000	11.95238

x) *The distribution of pathological lesions in Danebury Hillfort dog ABGs*

H_0 There is no significant difference in the skeletal distribution of pathological lesions in *dog* ABGs at Danebury hillfort

H_1There is a significant difference in the skeletal distribution of pathological lesions in *dog* ABGs at Danebury hillfort

X^2 = 21.0 p=.0001, p < 0.05, d.f. = 3

H_0 is rejected at $\alpha = 0.05$

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 21.00000 df = 3 p = .000105 NOTE: Unequal sums of obs. & exp. frequencies			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	1.00000	5.25000	-4.25000	3.44048
C: 2	2.00000	5.25000	-3.25000	2.01190
C: 3	14.00000	5.25000	8.75000	14.58333
C: 4	3.00000	5.25000	-2.25000	0.96429
Sum	20.00000	21.00000	-1.00000	21.00000

x) *The distribution of pathological lesions in Danebury Hillfort horse ABGs*

H_0 There is no significant difference in the skeletal distribution of pathological lesions in *horse* ABGs at Danebury hillfort (axial and appendicular)

H_1There is a significant difference in the skeletal distribution of pathological lesions in *horse* ABGs at Danebury hillfort

X^2 = 4.76 p=.0290, p < 0.05, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	Observed vs. Expected Frequencies (Spreadshee Chi-Square = 4.764706 df = 1 p = .029050			
Case	observed Var1	expected Var2	O - E	(O-E)**2 /E
C: 1	13.0000(	8.5000(	4.5000(	2.382353
C: 2	4.0000(	8.5000(	-4.5000(	2.382353
Sum	17.0000(	17.0000(	0.0000(	4.764706

x) *The frequency of IA cattle oral path vs. IA s/g oral path (combined ws and bf)*

H_0 There is no significant difference between the frequency of IA cattle oral path and IA S/G oral path

H_1 There is a significant difference between the frequency of IA cattle oral path and IA S/G oral path

$X^2 = 5.38$ p=.0204, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	11	1288	1299
Percent of total	.265%	31.029%	31.294%
Frequencies, row 2	51	2801	2852
Percent of total	1.229%	67.478%	68.706%
Column totals	62	4089	4151
Percent of total	1.494%	98.506%	
Chi-square (df=1)	5.38	p= .0204	
V-square (df=1)	5.37	p= .0204	
Yates corrected Chi-square	4.76	p= .0292	
Phi-square	.00130		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	2766.19	p=0.0000	
Chi-square (B/C)	1140.92	p=0.0000	

x) *The frequency of IA cattle trauma vs. IA s/g trauma (combined ws and bf)*

H_0 There is no significant difference between the frequency of IA cattle trauma and IA S/G trauma

H_1 There is a significant difference between the frequency of IA cattle trauma and IA S/G trauma

X^2 = 1.54 p=.2154, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	2	1297	1299
Percent of total	.048%	31.245%	31.294%
Frequencies, row 2	11	2841	2852
Percent of total	.265%	68.441%	68.706%
Column totals	13	4138	4151
Percent of total	.313%	99.687%	
Chi-square (df=1)	1.54	p= .2154	
V-square (df=1)	1.53	p= .2154	
Yates corrected Chi-square	.88	p= .3475	
Phi-square	.00037		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	2833.01	p=0.0000	
Chi-square (B/C)	1262.40	p=0.0000	

x) *The frequency of IA cattle arthropathy vs. IA s/g arthropathy (combined ws and bf)*

H_0 There is no significant difference between the frequency of IA cattle *arthropathy* and IA S/G *arthropathy*

H_1There is a significant difference between the frequency of IA cattle *arthropathy* and IA S/G *arthropathy*

X^2 = 31.20 p=.0000, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	19	1280	1299
Percent of total	.458%	30.836%	31.294%
Frequencies, row 2	3	2849	2852
Percent of total	.072%	68.634%	68.706%
Column totals	22	4129	4151
Percent of total	.530%	99.470%	
Chi-square (df=1)	31.20	p= .0000	
V-square (df=1)	31.19	p= .0000	
Yates corrected Chi-square	28.67	p= .0000	
Phi-square	.00752		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	2790.53	p=0.0000	
Chi-square (B/C)	1269.04	p=0.0000	

x) *The frequency of IA cattle congenital vs. IA s/g congenital (combined ws and bf)*

H_0 There is no significant difference between the frequency of IA cattle *congenital* and IA S/G *congenital*

H_1There is a significant difference between the frequency of IA cattle *congenital* and IA S/G *congenital*

X^2 = 7.12 p=.0076, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	6	1293	1299
Percent of total	.145%	31.149%	31.294%
Frequencies, row 2	2	2850	2852
Percent of total	.048%	68.658%	68.706%
Column totals	8	4143	4151
Percent of total	.193%	99.807%	
Chi-square (df=1)	7.12	p= .0076	
V-square (df=1)	7.12	p= .0076	
Yates corrected Chi-square	5.23	p= .0222	
Phi-square	.00172		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	2830.06	p=0.0000	
Chi-square (B/C)	1285.02	p=0.0000	

x) *The frequency of IA cattle nsbp vs. IA s/g nsbp (combined ws and bf)*

H_0 There is no significant difference between the frequency of IA cattle *nsbp* and IA S/G *nsbp*

H_1There is a significant difference between the frequency of IA cattle *nsbp* and IA S/G *nsbp*

X^2 = .56 p=.4536, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	13	1286	1299
Percent of total	.313%	30.980%	31.294%
Frequencies, row 2	22	2830	2852
Percent of total	.530%	68.176%	68.706%
Column totals	35	4116	4151
Percent of total	.843%	99.157%	
Chi-square (df=1)	.56	p= .4536	
V-square (df=1)	.56	p= .4536	
Yates corrected Chi-square	.32	p= .5711	
Phi-square	.00014		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	2789.26	p=0.0000	
Chi-square (B/C)	1219.55	p=0.0000	

x) *The frequency of IA cattle nsbl vs. IA s/g nsbl (combined ws and bf)*

H_0 There is no significant difference between the frequency of IA cattle *nsbl* and IA S/G *nsbl*

H_1 There is a significant difference between the frequency of IA cattle *nsbl* and IA S/G *nsbl*

$X^2 = 22.17$ p=.0000, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	16	1283	1299
Percent of total	.385%	30.908%	31.294%
Frequencies, row 2	4	2848	2852
Percent of total	.096%	68.610%	68.706%
Column totals	20	4131	4151
Percent of total	.482%	99.518%	
Chi-square (df=1)	22.17	p= .0000	
V-square (df=1)	22.17	p= .0000	
Yates corrected Chi-square	19.96	p= .0000	
Phi-square	.00534		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	2798.38	p=0.0000	
Chi-square (B/C)	1269.06	p=0.0000	

x) *The frequency of IA cattle ocm vs. IA s/g ocm (combined ws and bf)*

H_0 There is no significant difference between the frequency of IA cattle *ocm* and IA S/G *ocm*

H_1 There is a significant difference between the frequency of IA cattle *ocm* and IA S/G *ocm*

$X^2 = .75$ p=.3849, $p > 0.05$, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	5	1294	1299
Percent of total	.120%	31.173%	31.294%
Frequencies, row 2	17	2835	2852
Percent of total	.410%	68.297%	68.706%
Column totals	22	4129	4151
Percent of total	.530%	99.470%	
Chi-square (df=1)	.75	p= .3849	
V-square (df=1)	.75	p= .3850	
Yates corrected Chi-square	.41	p= .5233	
Phi-square	.00018		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	2818.04	p=0.0000	
Chi-square (B/C)	1241.93	p=0.0000	

x) *The frequency of pathological IA cattle vs. pathological IA S/G (WS, BF combined)*

H_0 There is no significant difference between the frequency of path IA cattle and path IA S/G

H_1 There is a significant difference between the frequency of path IA cattle and path IA S/G

$X^2 = 5.62$ p=.0177, $p < 0.05$, d.f. = 1

H_0 is rejected at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	69	1230	1299
Percent of total	1.662%	29.631%	31.294%
Frequencies, row 2	106	2746	2852
Percent of total	2.554%	66.153%	68.706%
Column totals	175	3976	4151
Percent of total	4.216%	95.784%	
Chi-square (df=1)	5.62	p= .0177	
V-square (df=1)	5.62	p= .0177	
Yates corrected Chi-square	5.24	p= .0221	
Phi-square	.00135		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	2543.86	p=0.0000	
Chi-square (B/C)	943.96	p=0.0000	

x) *The frequency of VA cattle trauma vs. VA s/g trauma (combined hft and svk)*

H_0 There is no significant difference between the frequency of VA cattle *trauma* and vA S/G *trauma*

H_1There is a significant difference between the frequency of VA cattle *trauma* and v A S/G *trauma*

X^2 = .00 p=.9545, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	4	3950	3954
Percent of total	.024%	24.097%	24.122%
Frequencies, row 2	13	12425	12438
Percent of total	.079%	75.799%	75.878%
Column totals	17	16375	16392
Percent of total	.104%	99.896%	
Chi-square (df=1)	.00	p= .9545	
V-square (df=1)	.00	p= .9545	
Yates corrected Chi-square	.05	p= .8208	
Phi-square	.00000		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12411.0	p=0.0000	
Chi-square (B/C)	3909.18	p=0.0000	

x) *The frequency of VA cattle arth vs. VA s/g arth (combined hft and svk)*

H_0 There is no significant difference between the frequency of VA cattle *arth* and vA S/G *arth*

H_1There is a significant difference between the frequency of VA cattle *arth* and v A S/G *arth*

X^2 = 113.42 p=.0000, p< 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	47	3907	3954
Percent of total	.287%	23.835%	24.122%
Frequencies, row 2	8	12430	12438
Percent of total	.049%	75.830%	75.878%
Column totals	55	16337	16392
Percent of total	.336%	99.664%	
Chi-square (df=1)	113.42	p=0.0000	
V-square (df=1)	113.41	p=0.0000	
Yates corrected Chi-square	110.08	p=0.0000	
Phi-square	.00692		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12287.7	p=0.0000	
Chi-square (B/C)	3881.07	p=0.0000	

x) *The frequency of VA cattle cong vs. VA s/g cong (combined hft and svk)*

H_0 There is no significant difference between the frequency of VA cattle *cong* and vA S/G *cong*

H_1There is a significant difference between the frequency of VA cattle *cong* and v A S/G *cong*

X^2 = 2.02 p=.1553, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	5	3949	3954
Percent of total	.031%	24.091%	24.122%
Frequencies, row 2	7	12431	12438
Percent of total	.043%	75.836%	75.878%
Column totals	12	16380	16392
Percent of total	.073%	99.927%	
Chi-square (df=1)	2.02	p= .1553	
V-square (df=1)	2.02	p= .1553	
Yates corrected Chi-square	1.17	p= .2785	
Phi-square	.00012		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12414.0	p=0.0000	
Chi-square (B/C)	3926.06	p=0.0000	

x) *The frequency of VA cattle nsbp vs. VA s/g nsbp (combined hft and svk)*

H_0 There is no significant difference between the frequency of VA cattle *nsbp* and vA S/G *nsbp*

H_1There is a significant difference between the frequency of VA cattle *nsbp* and v A S/G *nsbp*

X^2 = .11 p=.7383, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	7	3947	3954
Percent of total	.043%	24.079%	24.122%
Frequencies, row 2	19	12419	12438
Percent of total	.116%	75.763%	75.878%
Column totals	26	16366	16392
Percent of total	.159%	99.841%	
Chi-square (df=1)	.11	p= .7383	
V-square (df=1)	.11	p= .7383	
Yates corrected Chi-square	.01	p= .9165	
Phi-square	.00001		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12396.0	p=0.0000	
Chi-square (B/C)	3888.38	p=0.0000	

x) *The frequency of VA cattle nsbl vs. VA s/g nsbl (combined hft and svk)*

H_0 There is no significant difference between the frequency of VA cattle *nsbl* and vA S/G *nsbl*

H_1There is a significant difference between the frequency of VA cattle *nsbl* and v A S/G *nsbl*

X^2 = .04 p=.8505, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	4	3950	3954
Percent of total	.024%	24.097%	24.122%
Frequencies, row 2	14	12424	12438
Percent of total	.085%	75.793%	75.878%
Column totals	18	16374	16392
Percent of total	.110%	99.890%	
Chi-square (df=1)	.04	p= .8505	
V-square (df=1)	.04	p= .8505	
Yates corrected Chi-square	.01	p= .9305	
Phi-square	.00000		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12410.0	p=0.0000	
Chi-square (B/C)	3906.21	p=0.0000	

x) *The frequency of VA cattle ocm vs. VA s/g ocm (combined hft and svk)*

H_0 There is no significant difference between the frequency of VA cattle *ocm* and vA S/G *ocm*

H_1There is a significant difference between the frequency of VA cattle *ocm* and v A S/G *ocm*

X^2 = 11.42 p=.0007, p < 0.05, d.f. = 1

H_0 is rejected at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	3	3951	3954
Percent of total	.018%	24.103%	24.122%
Frequencies, row 2	55	12383	12438
Percent of total	.336%	75.543%	75.878%
Column totals	58	16334	16392
Percent of total	.354%	99.646%	
Chi-square (df=1)	11.42	p= .0007	
V-square (df=1)	11.42	p= .0007	
Yates corrected Chi-square	10.40	p= .0013	
Phi-square	.00070		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12372.0	p=0.0000	
Chi-square (B/C)	3787.08	p=0.0000	

x) *The frequency of pathological VA cattle vs. pathological VA S/G (WS, BF combined)*

H_0 There is no significant difference between the frequency of path VA cattle and path vA S/G

H_1There is a significant difference between the frequency of path VA cattle and path vA S/G

X^2 = .83 p=.3618, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	59	3895	3954
Percent of total	.360%	23.762%	24.122%
Frequencies, row 2	212	12226	12438
Percent of total	1.293%	74.585%	75.878%
Column totals	271	16121	16392
Percent of total	1.653%	98.347%	
Chi-square (df=1)	.83	p= .3618	
V-square (df=1)	.83	p= .3618	
Yates corrected Chi-square	.71	p= .4007	
Phi-square	.00005		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12048.2	p=0.0000	
Chi-square (B/C)	3300.98	p=0.0000	

x) *The frequency of oral path IA cattle vs. oral path VA S/G (all combined)*

H_0 There is no significant difference between the frequency of oral path IA cattle and path VA S/G

H_1There is a significant difference between the frequency of oral path IA cattle and oral path VA S/G

X^2 = .68 p=.4111, p > 0.05, d.f. = 1

H_0 is accepted at $\alpha = 0.05$

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	11	1288	1299
Percent of total	.080%	9.376%	9.456%
Frequencies, row 2	136	12302	12438
Percent of total	.990%	89.554%	90.544%
Column totals	147	13590	13737
Percent of total	1.070%	98.930%	
Chi-square (df=1)	.68	p= .4111	
V-square (df=1)	.68	p= .4111	
Yates corrected Chi-square	.46	p= .4963	
Phi-square	.00005		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12267.0	p=0.0000	
Chi-square (B/C)	930.34	p=0.0000	

x) *The frequency of trauma IA cattle vs.trauma VA S/G (all combined)*

H_0 There is no significant difference between the frequency of trauma IA cattle and trauma VA S/G

H_1There is a significant difference between the frequency of trauma IA cattle and trauma VA S/G

X^2 = .26 p=.6076, p > 0.05, d.f. = 1

H_0 is accepted at α = 0.05

	2 x 2 Table (Spreadsheet1)		
	Column 1	Column 2	Row Totals
Frequencies, row 1	2	1297	1299
Percent of total	.015%	9.442%	9.456%
Frequencies, row 2	13	12425	12438
Percent of total	.095%	90.449%	90.544%
Column totals	15	13722	13737
Percent of total	.109%	99.891%	
Chi-square (df=1)	.26	p= .6076	
V-square (df=1)	.26	p= .6076	
Yates corrected Chi-square	.01	p= .9426	
Phi-square	.00002		
Fisher exact p, one-tailed		----	
two-tailed		----	
McNemar Chi-square (A/D)	12417.0	p=0.0000	
Chi-square (B/C)	1256.56	p=0.0000	